Summer Conference Results from CMS: a look at a selected set of analyses

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on behalf of the CMS collaboration

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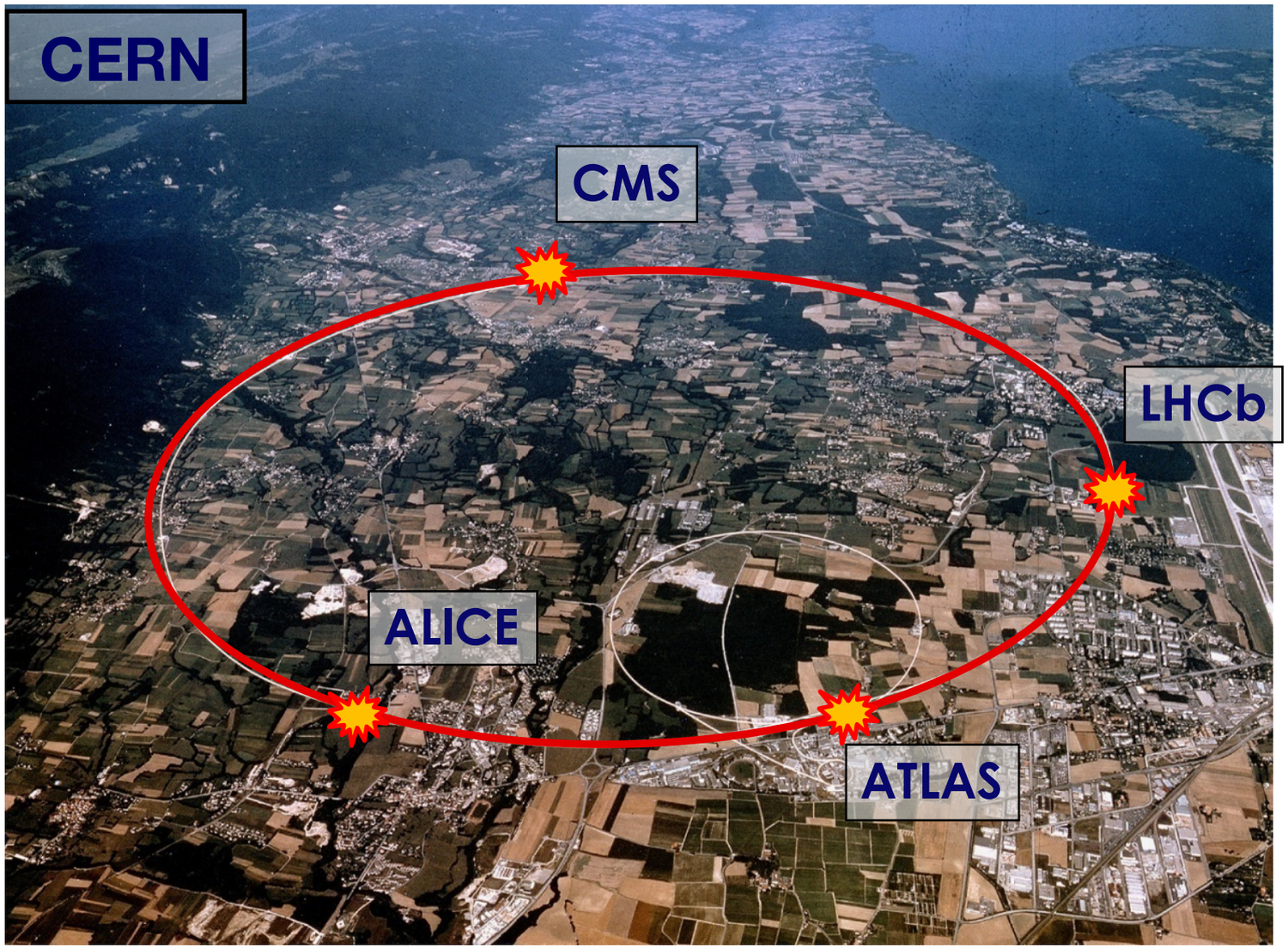
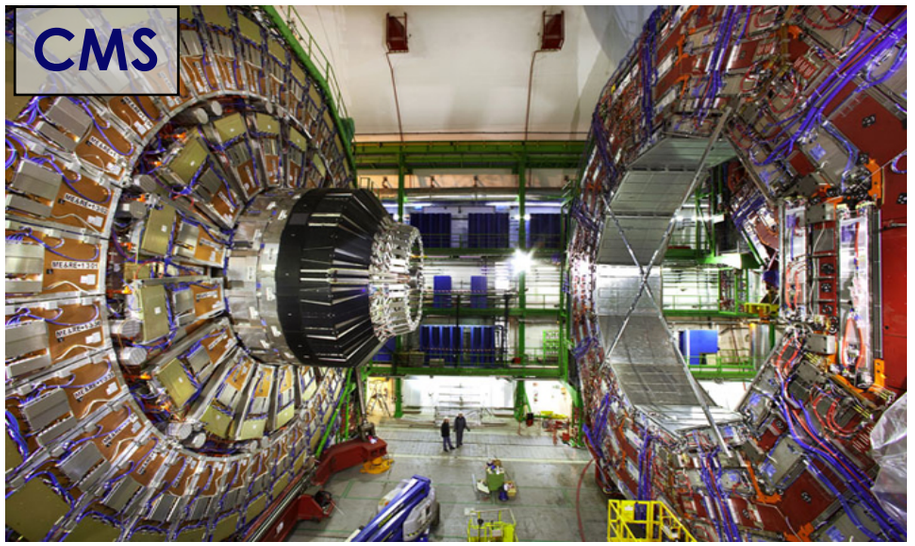
C.E.R.N. and the LHC

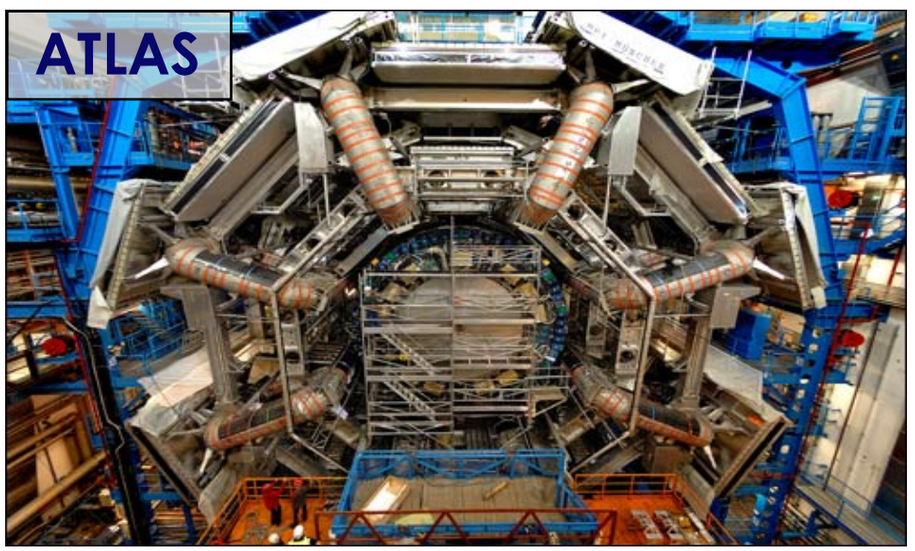
Large number of H.E.P. projects

- Astrophysics
- Dark Matter searches
- Collider

- **Large Hadron Collider**
  - Proton-proton collider, radius = 4.3 Km.
  - Two multi-purpose detectors: CMS & ATLAS.
  - Plus other specialized detectors: ALICE, LHCb, TOTEM, MoEDAL and LHCf

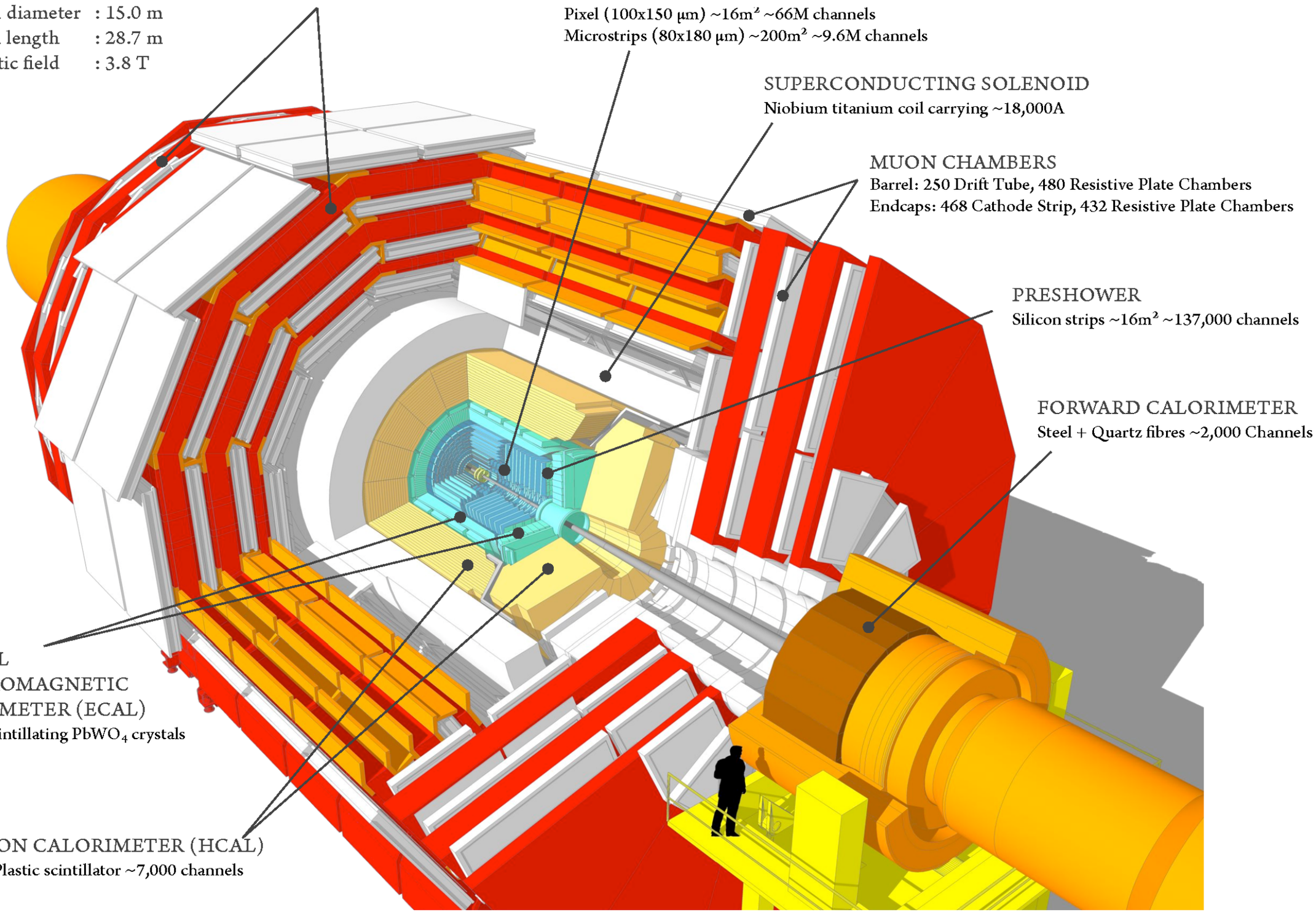






CMS Detector

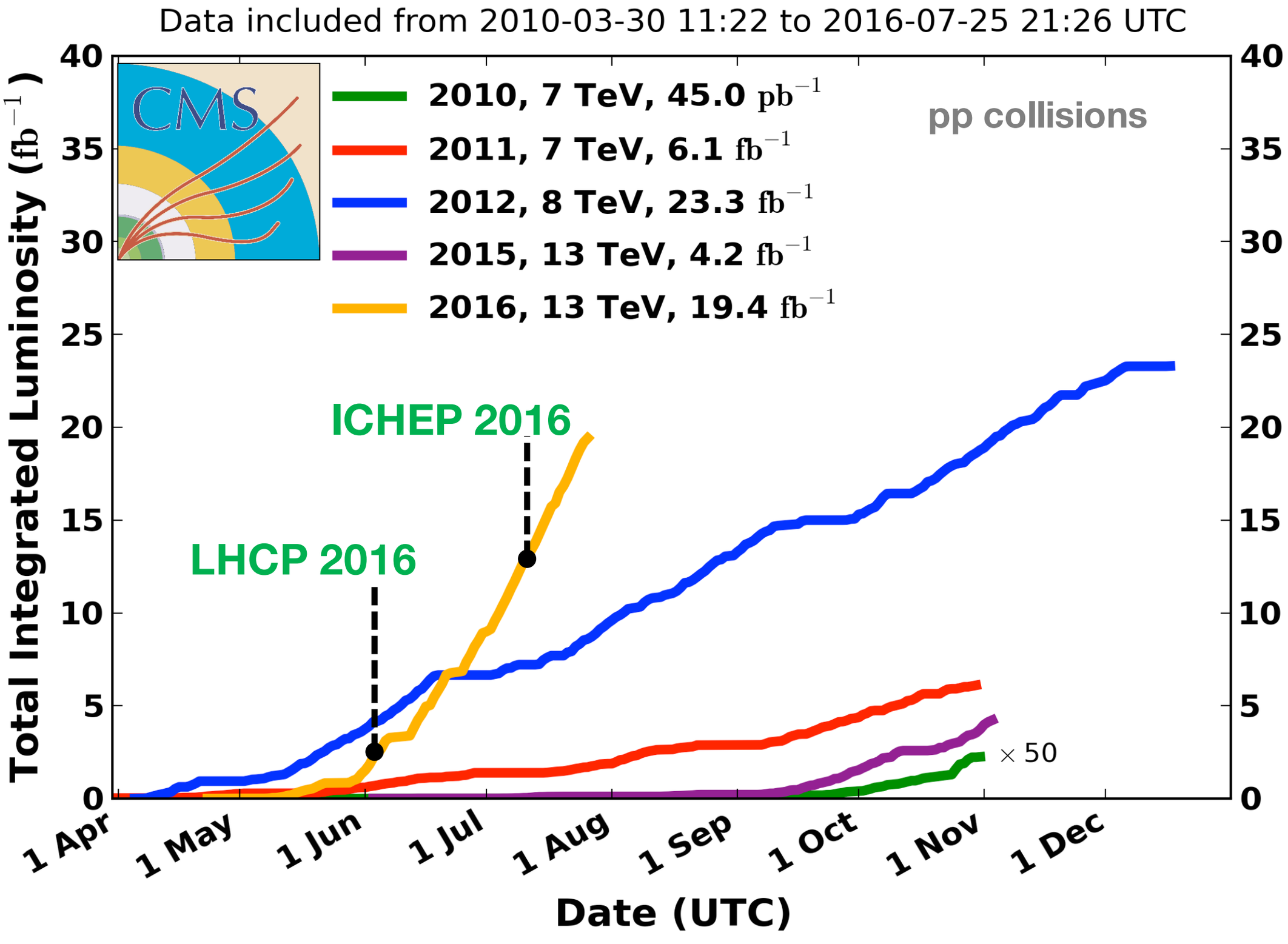
Total weight : 14,000 tonnes
Overall diameter : 15.0 m
Overall length : 28.7 m
Magnetic field : 3.8 T



CMS Collaboration: 180 institutions, 43 countries

- 1789 physicists
- 891 Ph.D students
- 859 engineers
- 281 technicians

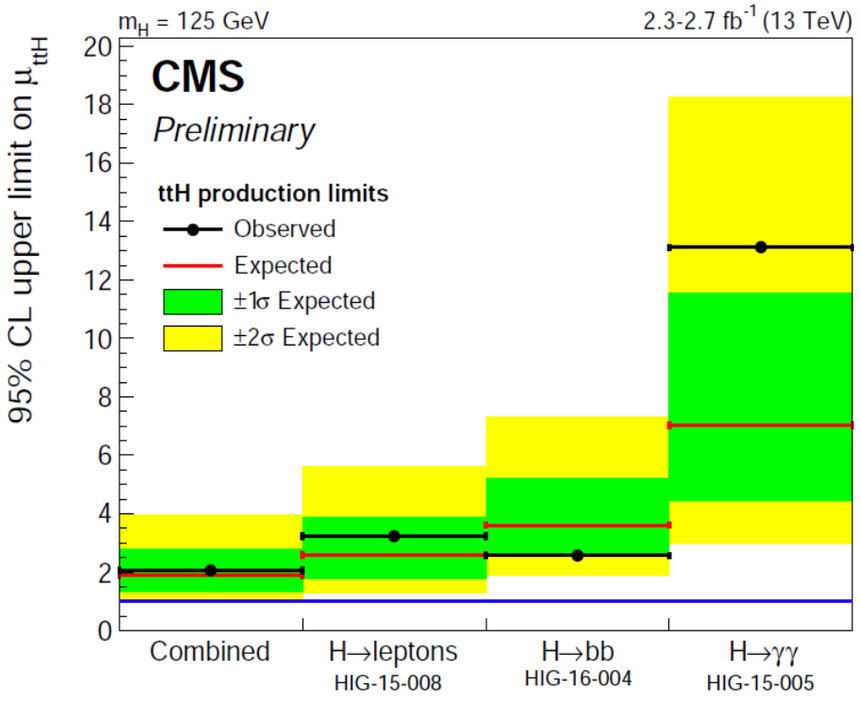
CMS Data is pouring in…

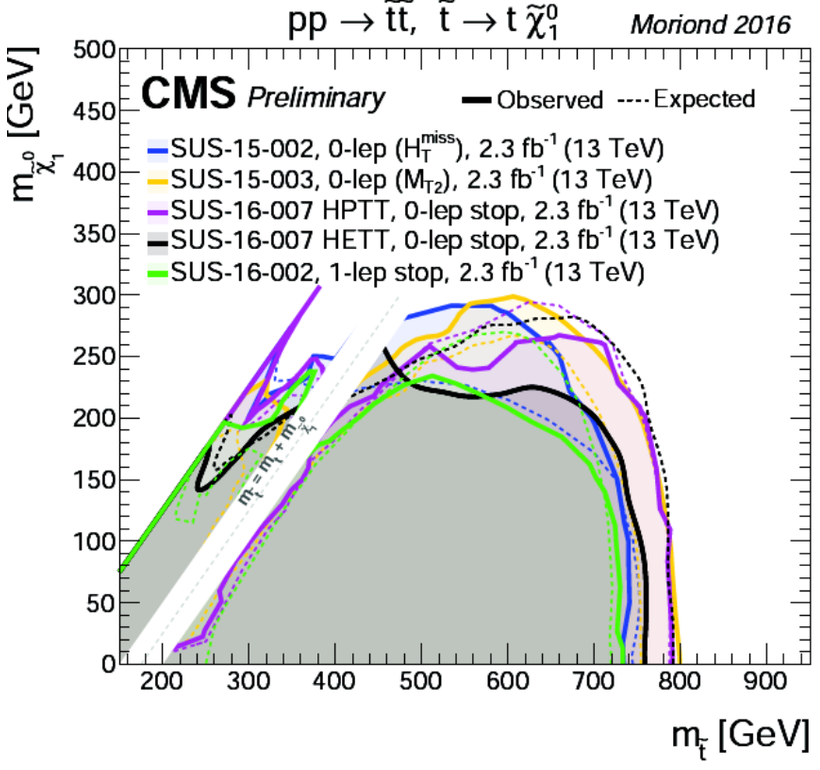


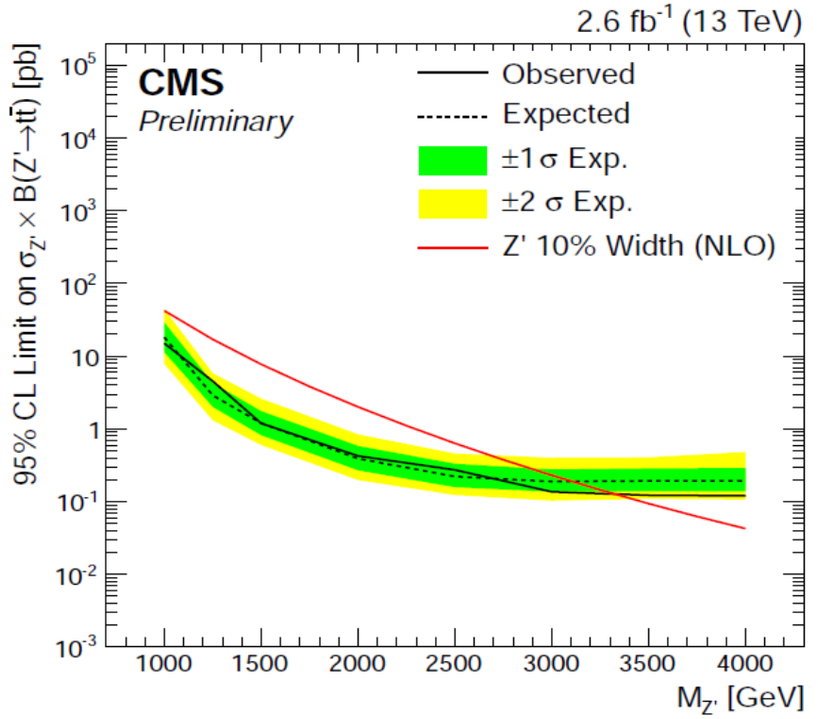
Where we left of …

LHCP 2016 , June 13th, 2016. Lund, Sweden.

- Presented an array of new analyses based on 2.3-2.7 fb^{-1} at 13 TeV.
  - Standard XS measurements: Ttbar, W, Z, WZ, ZZ, etc
  - Higgs searches to di-photon, multi-leptons and invisible
  - Sparticle searches
  - Searches for exotic Z' and $X_{5/3}$ particles.





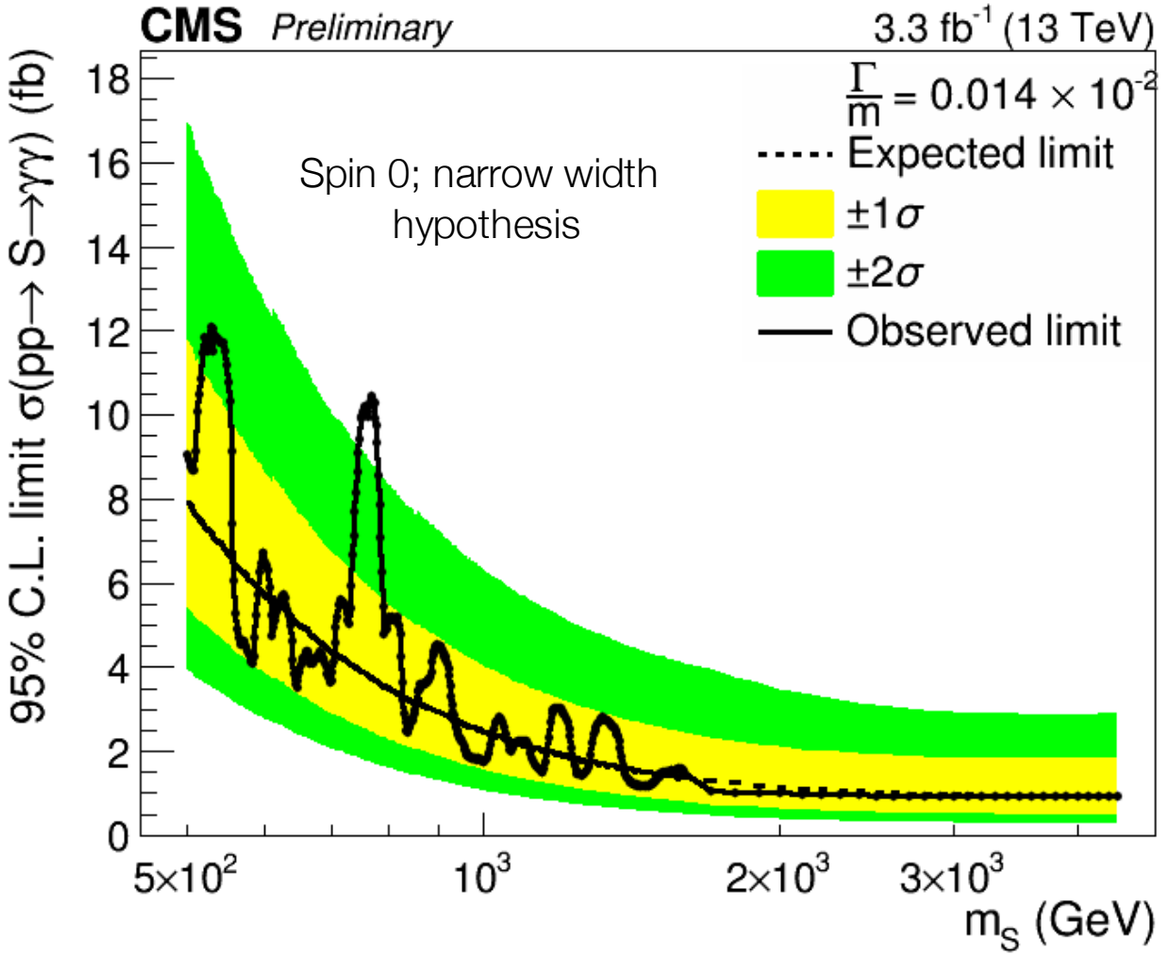


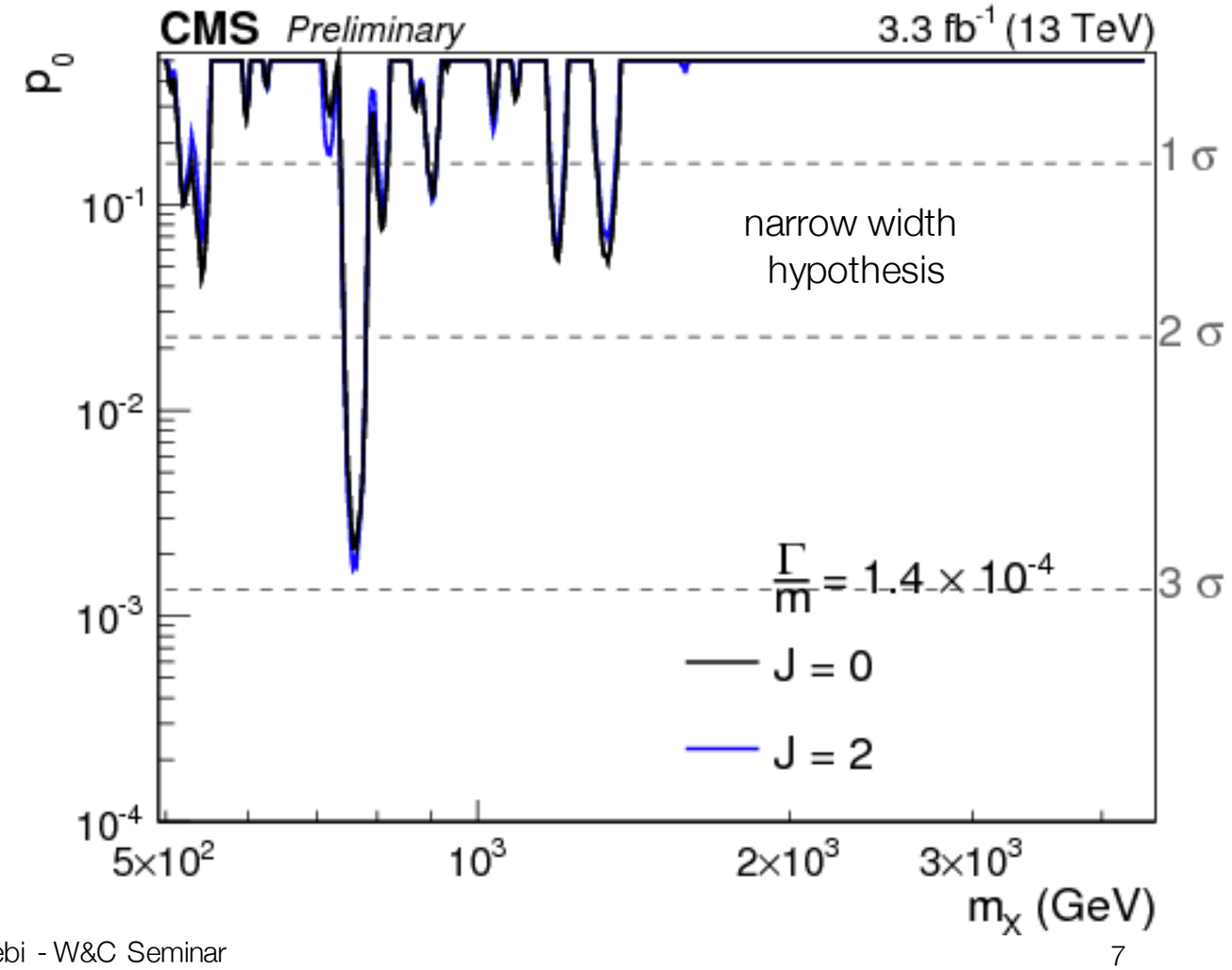
Where we left of …

LHCP 2016 , June 13th, 2016. Lund, Sweden.

CMS PAS EXO–16-018

- Analysis on X(750)→γγ excess remained strong.
  - Added 0 B-field data ➔ sensitivity increased 10%,
  - Local 2.8 sigma @13 TeV.
  - Adding 8 TeV data→local sig. to 3.4 sigma, global to 1.6 sigma





Plethora of new CMS results with 13 fb^{-1} at 13 TeV.

- Just new for ICHEP 2016, more than 70 new results !!

In this talk

- Resonances
  - Di-Jet
  - Di-Photon
  - Di-Lepton
- Higgs
  - Rediscovery
  - Properties
- Dark-Matter searches
  - Mono-Jet and Mono-V
  - DM summary
- SUSY
  - All-Hadronic
  - Combination with Leptons

- Can’t cover all new analyses ➔ “crazily selective”
- I will focus on results not on methodology
- Devil is in the details. Check all of them from CMS public page: https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResults

Resonances

Some new resonance analyses for ICHEP 2016

EXO-16-015 *Search for excited quarks in the γ+jet final state in pp collisions at √s= 13 TeV*
EXO-16-009 *Search for excited leptons in llgamma final state at 13 TeV*
EXO-16-025 *Search for high-mass resonances in Z(qq)gamma final state at 8 TeV*
EXO-16-027 *Search for high-mass resonances in diphoton final state using 2016 data*
EXO-16-031 *Search for high-mass resonances in dilepton final state with 2016 data*
EXO-16-032 *Search for high-mass resonances in dijet final state with 2016 data*
EXO-16-034 *Search for high-mass resonances in Z(ll)gamma final states with 2016 data*
EXO-16-035 *Search for high-mass resonances in Z(qq)gamma final state with 2016 data*

Dijet resonances

CMS EXO-16-032

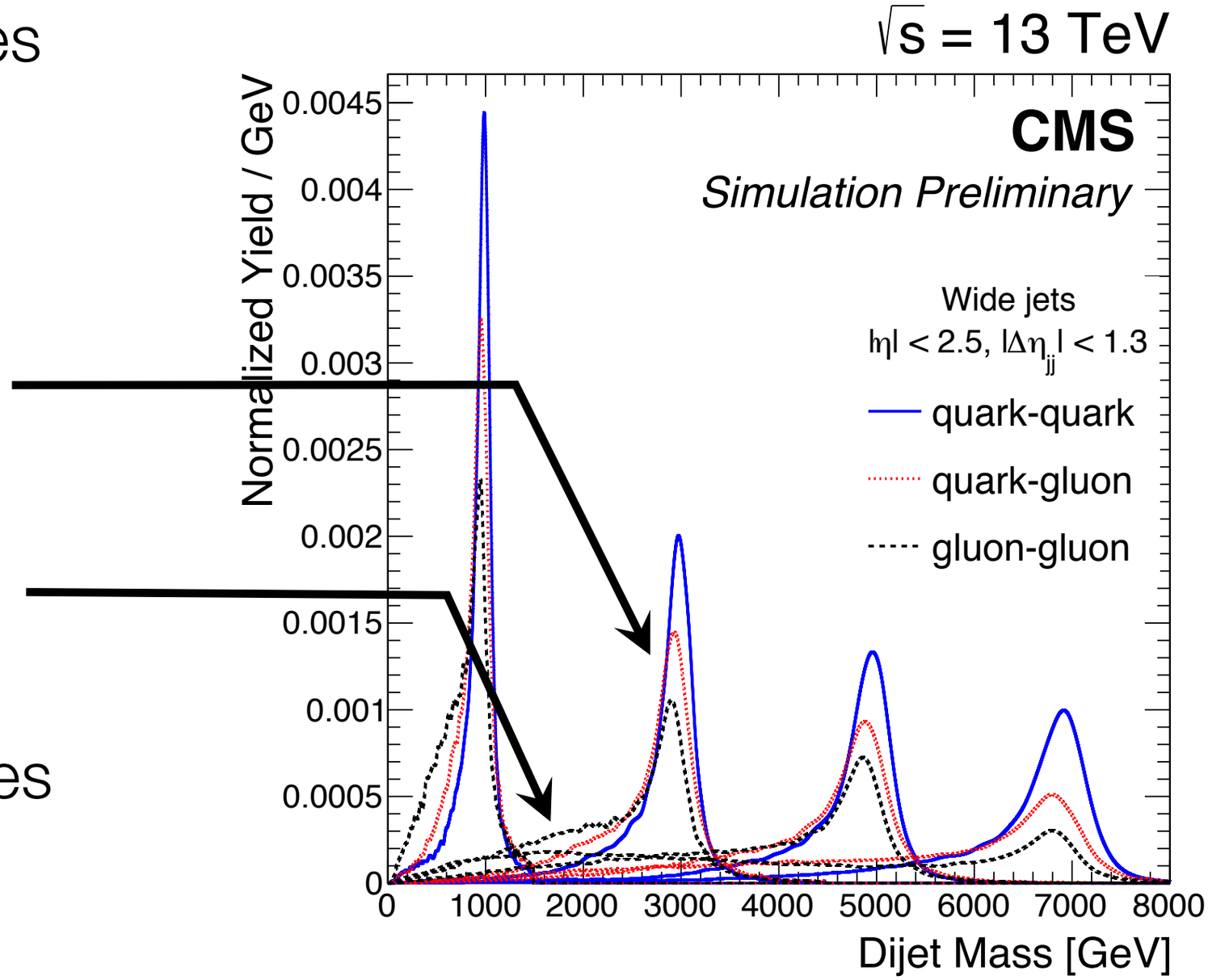
- Predicted by BSM models: axigluons, colorons, scalar diquarks, W′ and Z′ bosons, excited quarks, color-octet scalars, string resonances, RS, etc.
- early-detection signatures for new physics

<u>Typical dijet lineshape:</u>

- Gaussian cores from detector resolution
- Tails primarily from QCD radiation.

- Consider three final states

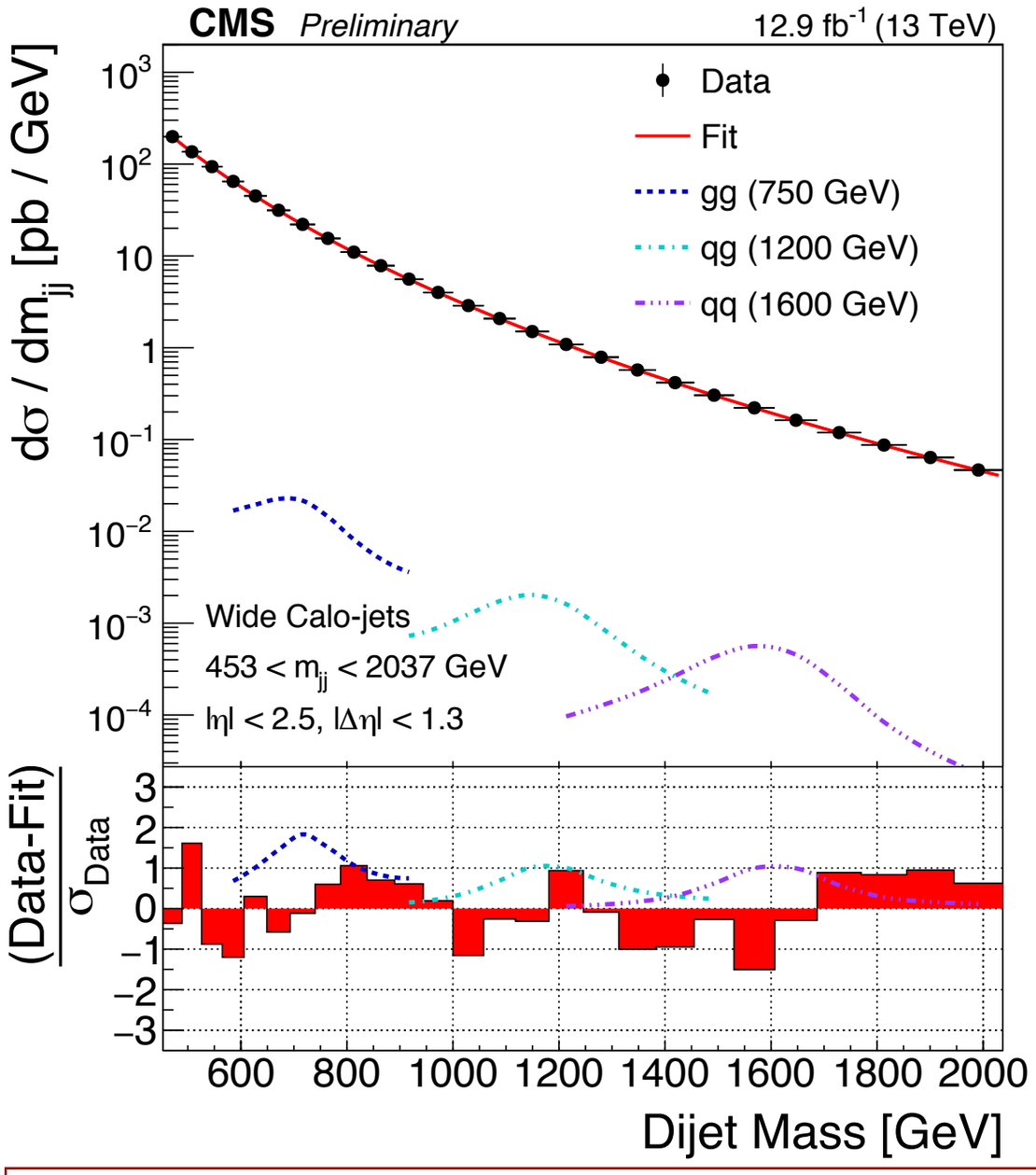
  qq, qg, gg

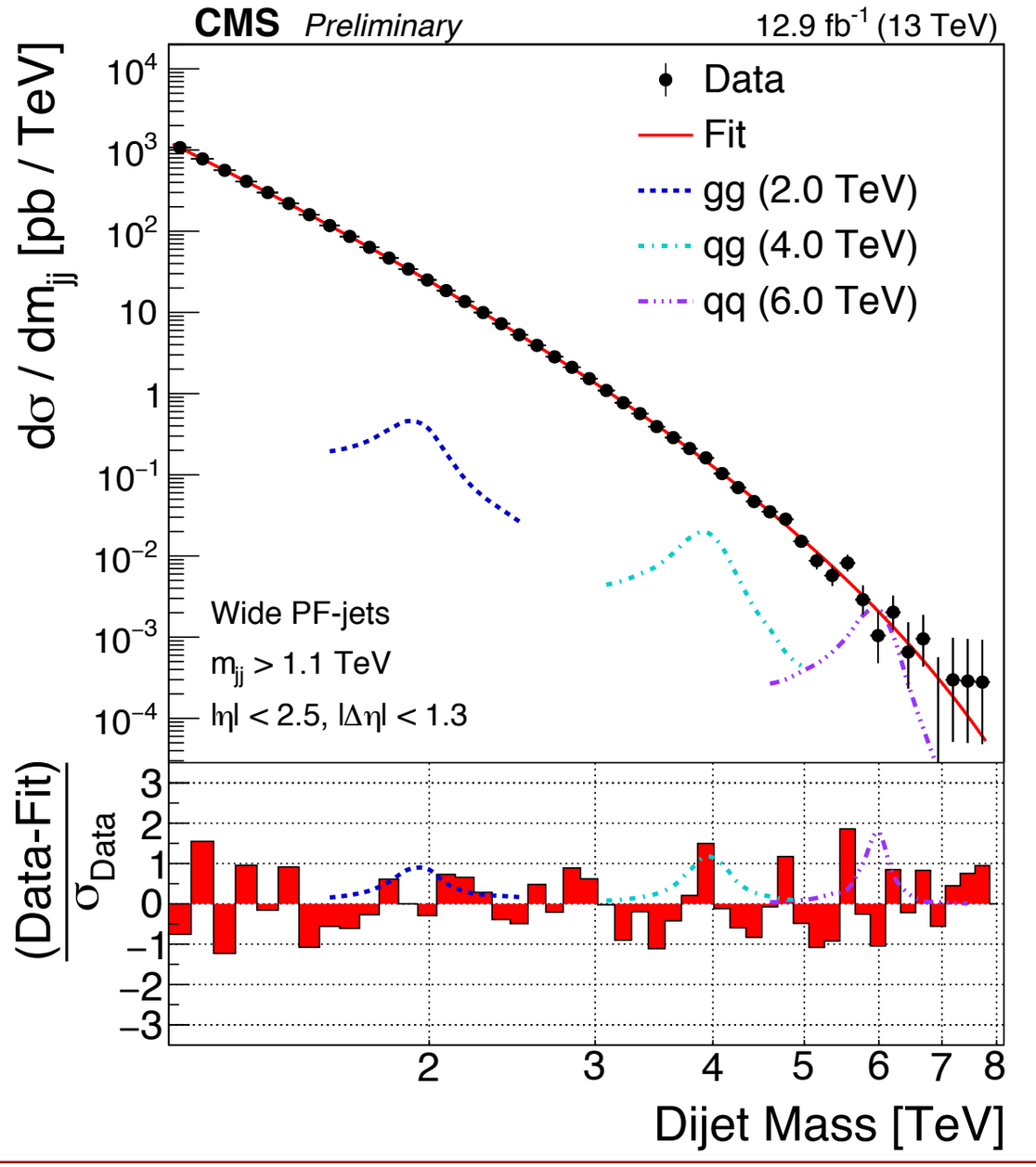


Dijet resonances

CMS EXO-16-032

- Dedicated low- and high-mass channels.



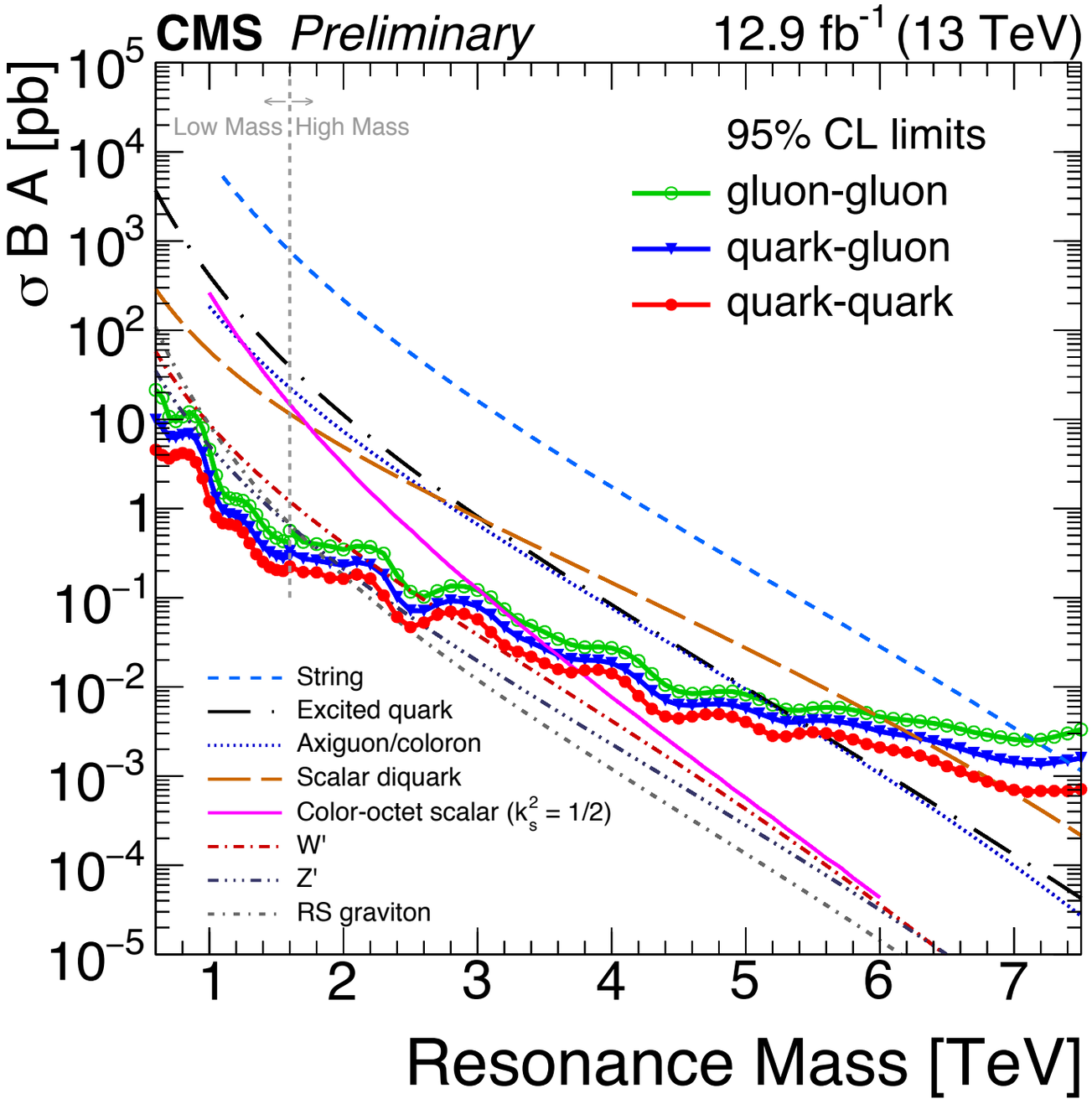


Great baseline fits for SM background

Dijet resonances: Limits

CMS EXO-16-032

- For most of the favorite models…



Dijet resonances: Limits

CMS EXO-16-032

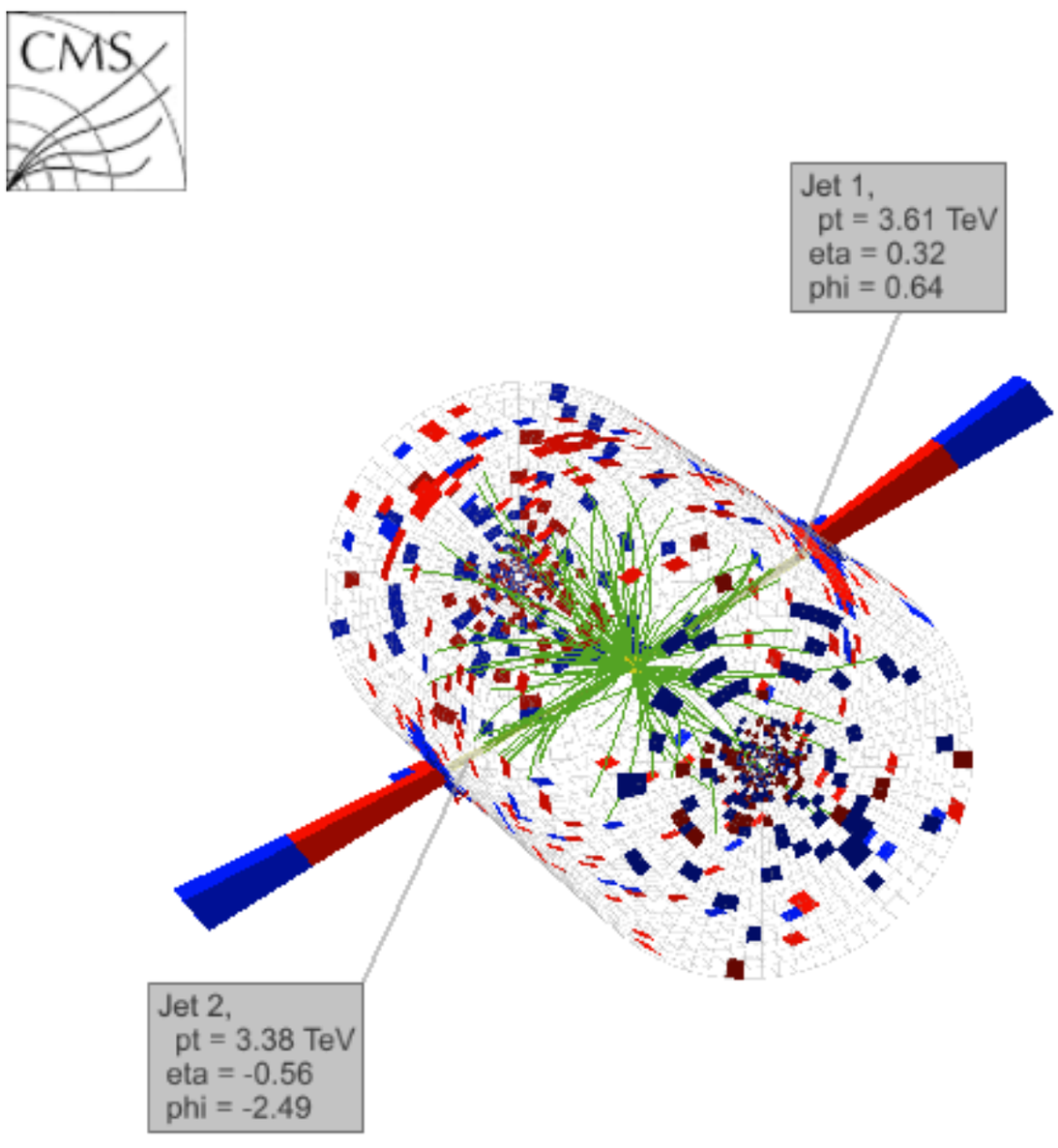
- For most of the favorite models…

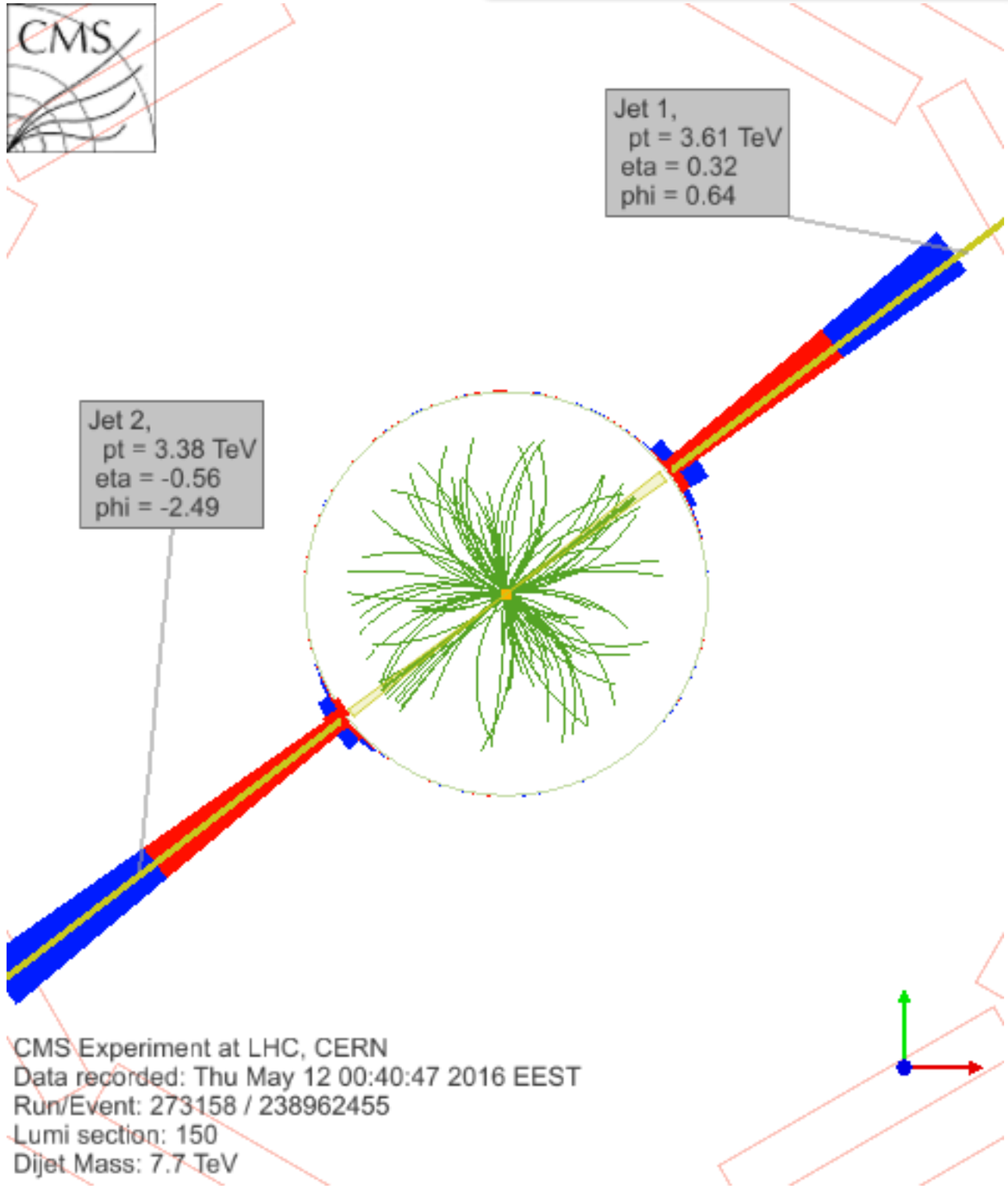
Model	Final State	Observed (expected) mass limit [TeV] $12.9\,\text{fb}^{-1}$ 13 TeV	$2.4\,\text{fb}^{-1}$ 13 TeV	$20\,\text{fb}^{-1}$ 8 TeV
String	qg	7.4 (7.4)	7.0 (6.9)	5.0 (4.9)
Scalar diquark	qq	6.9 (6.8)	6.0 (6.1)	4.7 (4.4)
Axigluon/coloron	$q\bar{q}$	5.5 (5.6)	5.1 (5.1)	3.7 (3.9)
Excited quark	qg	5.4 (5.4)	5.0 (4.8)	3.5 (3.7)
Color-octet scalar ($k_s^2 = 1/2$)	gg	3.0 (3.3)	—	—
W'	$q\bar{q}$	2.7 (3.1)	2.6 (2.3)	2.2 (2.2)
Z'	$q\bar{q}$	2.1 (2.3)	—	1.7 (1.8)
RS Graviton	$q\bar{q}$, gg	1.9 (1.8)	—	1.6 (1.3)

Increase in all limits due to larger statistics
Excluding string resonances up to 7.4 TeV

Dijet resonances: highest dijet invariant mass.

CMS EXO-16-032

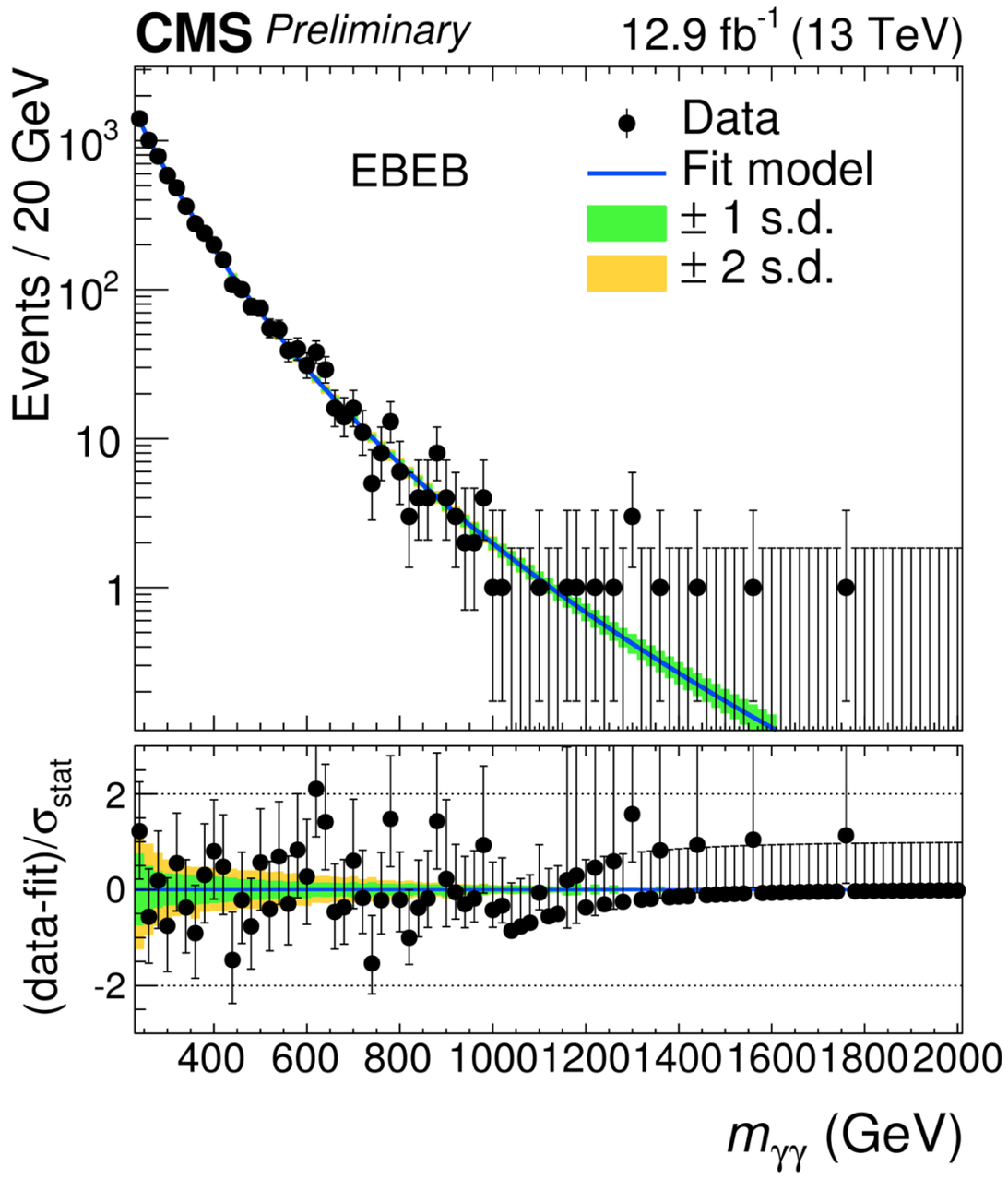




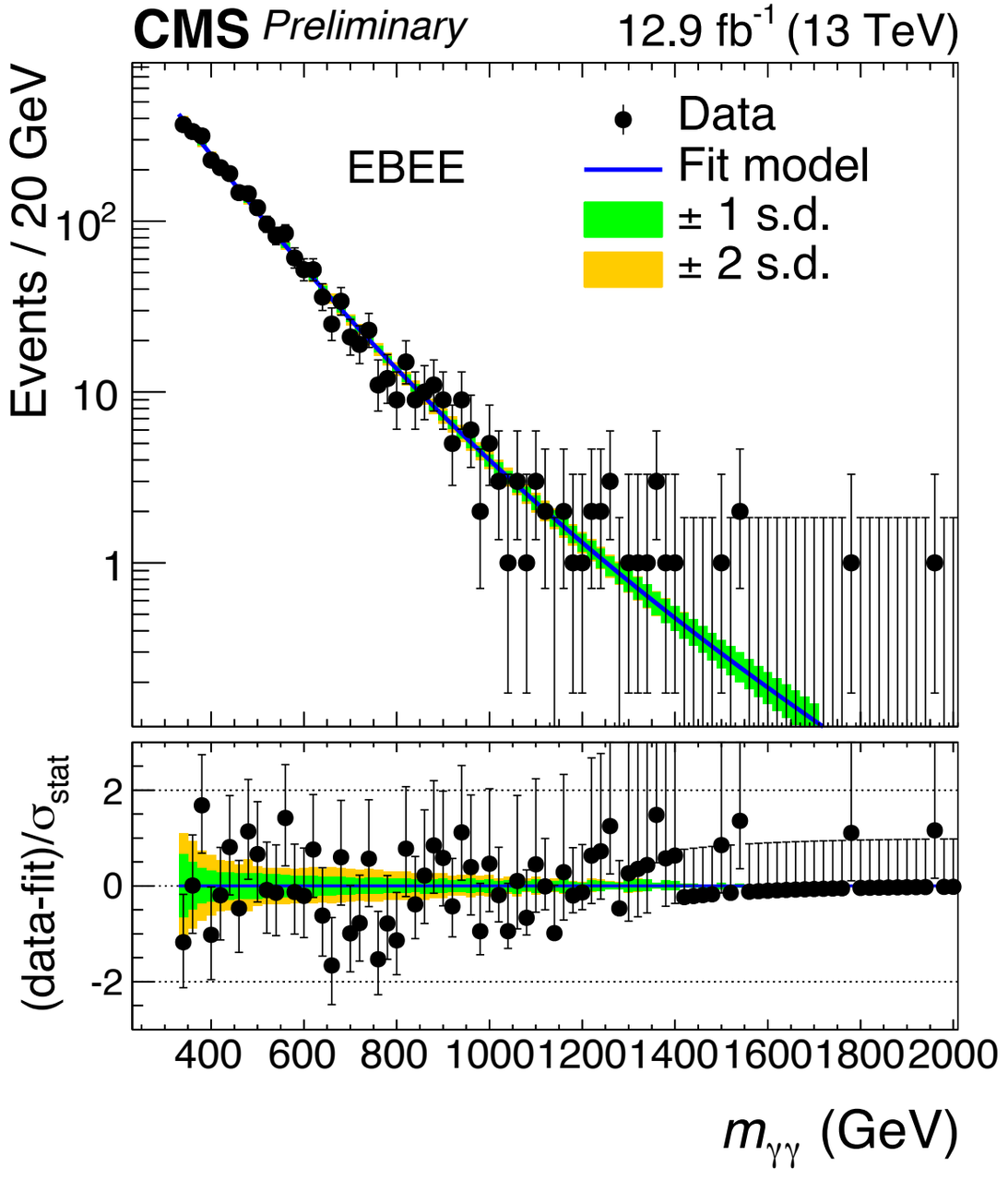
Di-photon resonances

- Central-Central

CMS PAS EXO-16-027



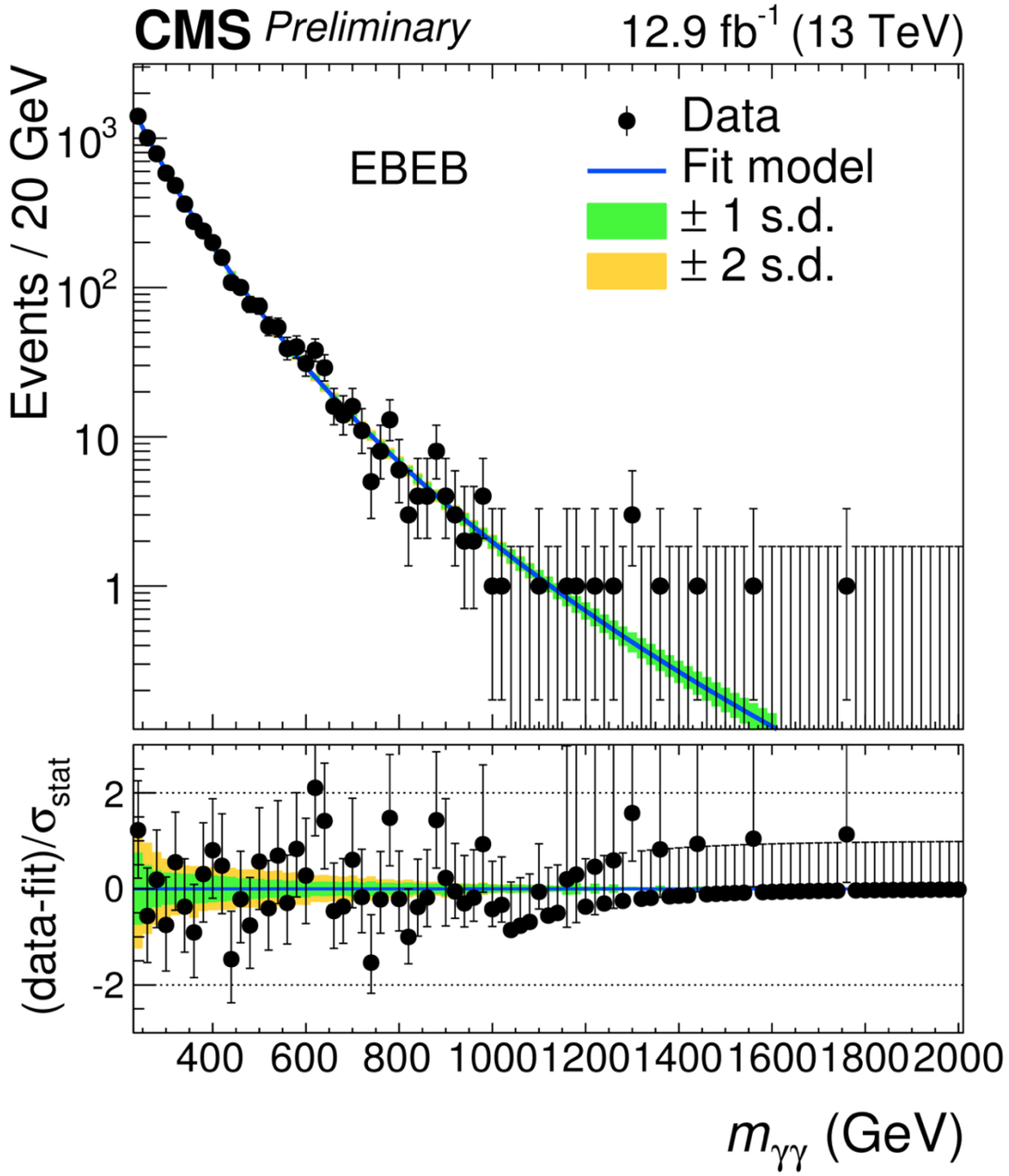
- Central-Endcap



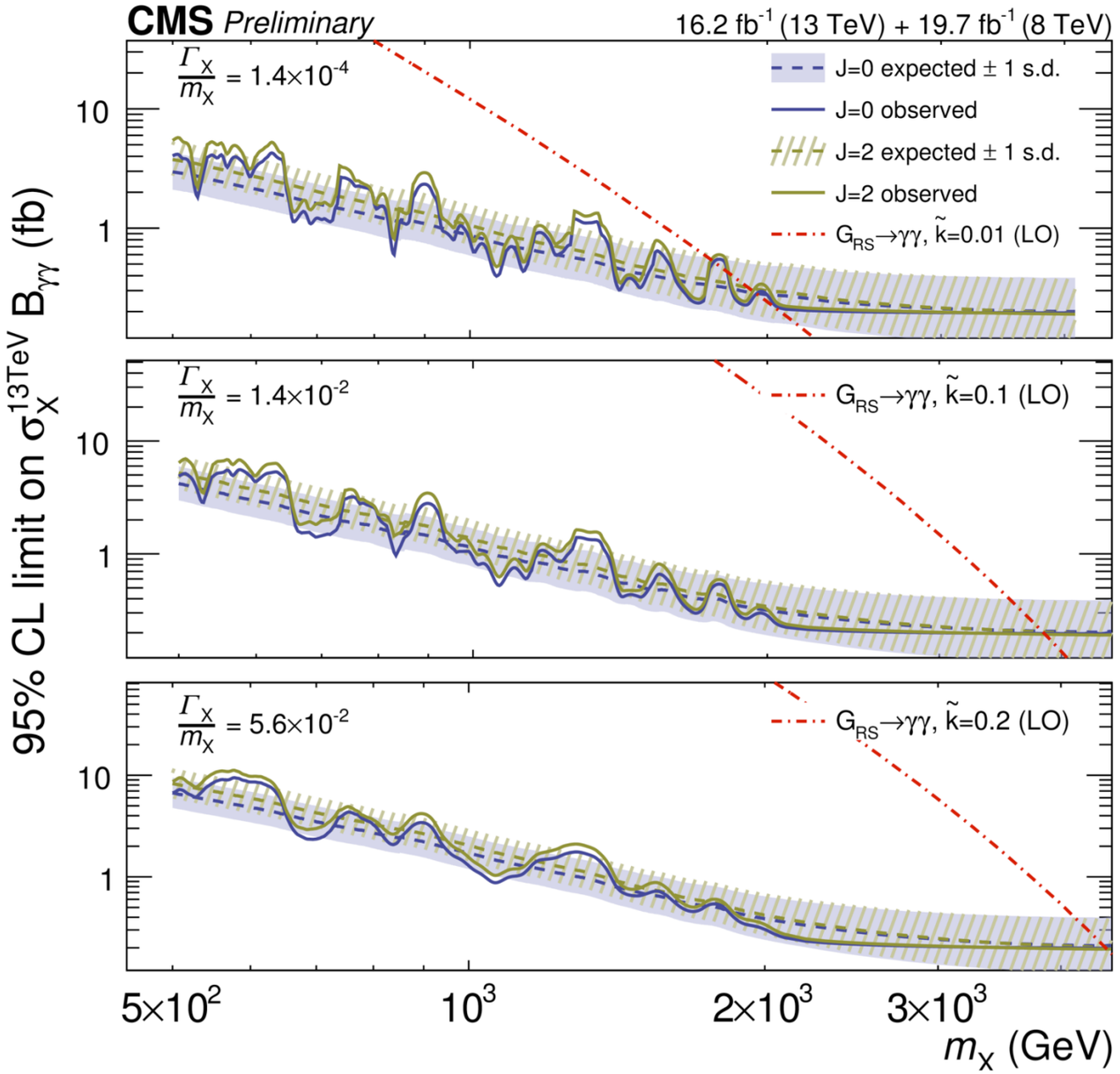
Di-photon resonance

- Di-photon spectrum

CMS PAS EXO-16-027



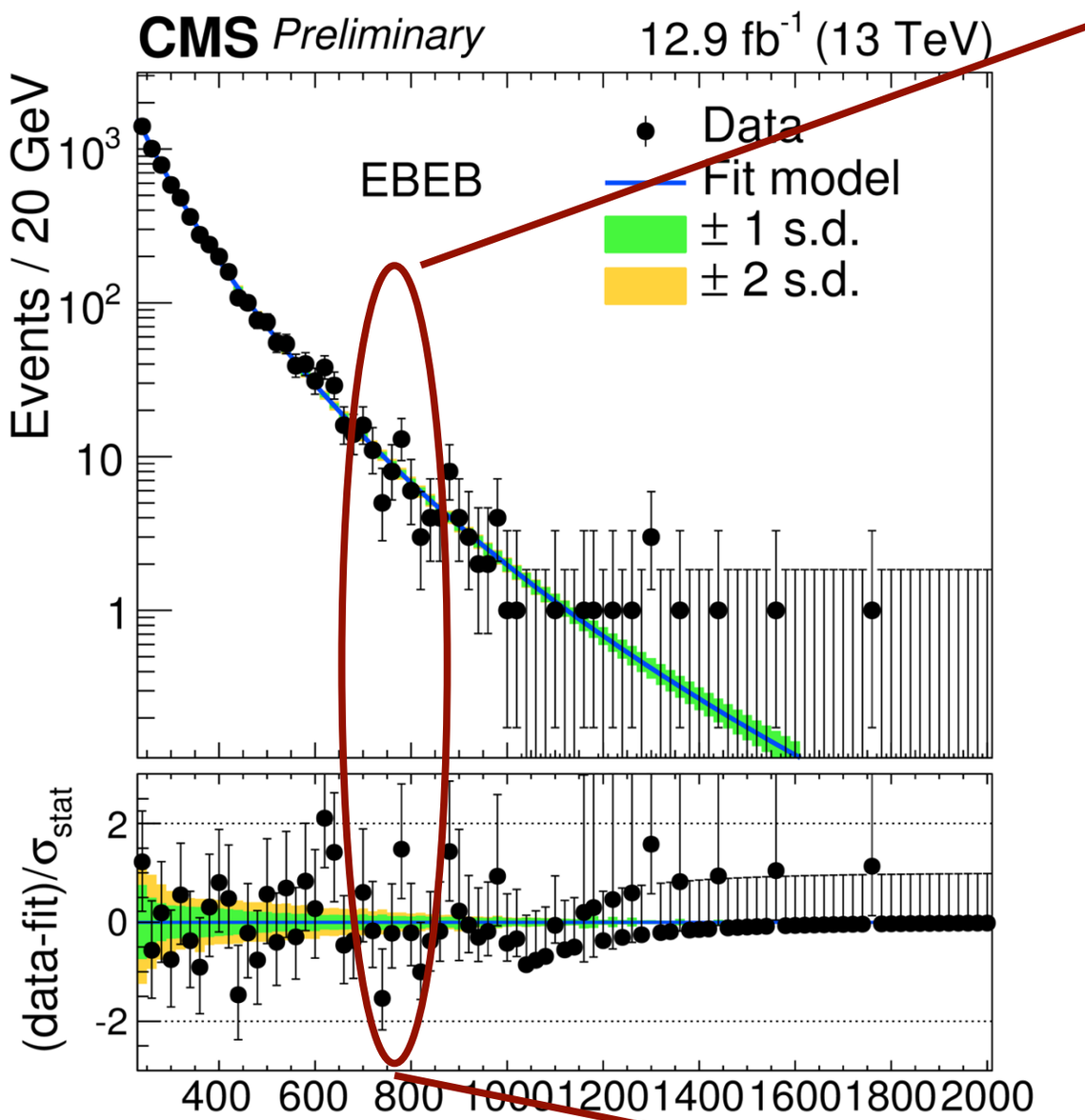
- Combine and set Limits



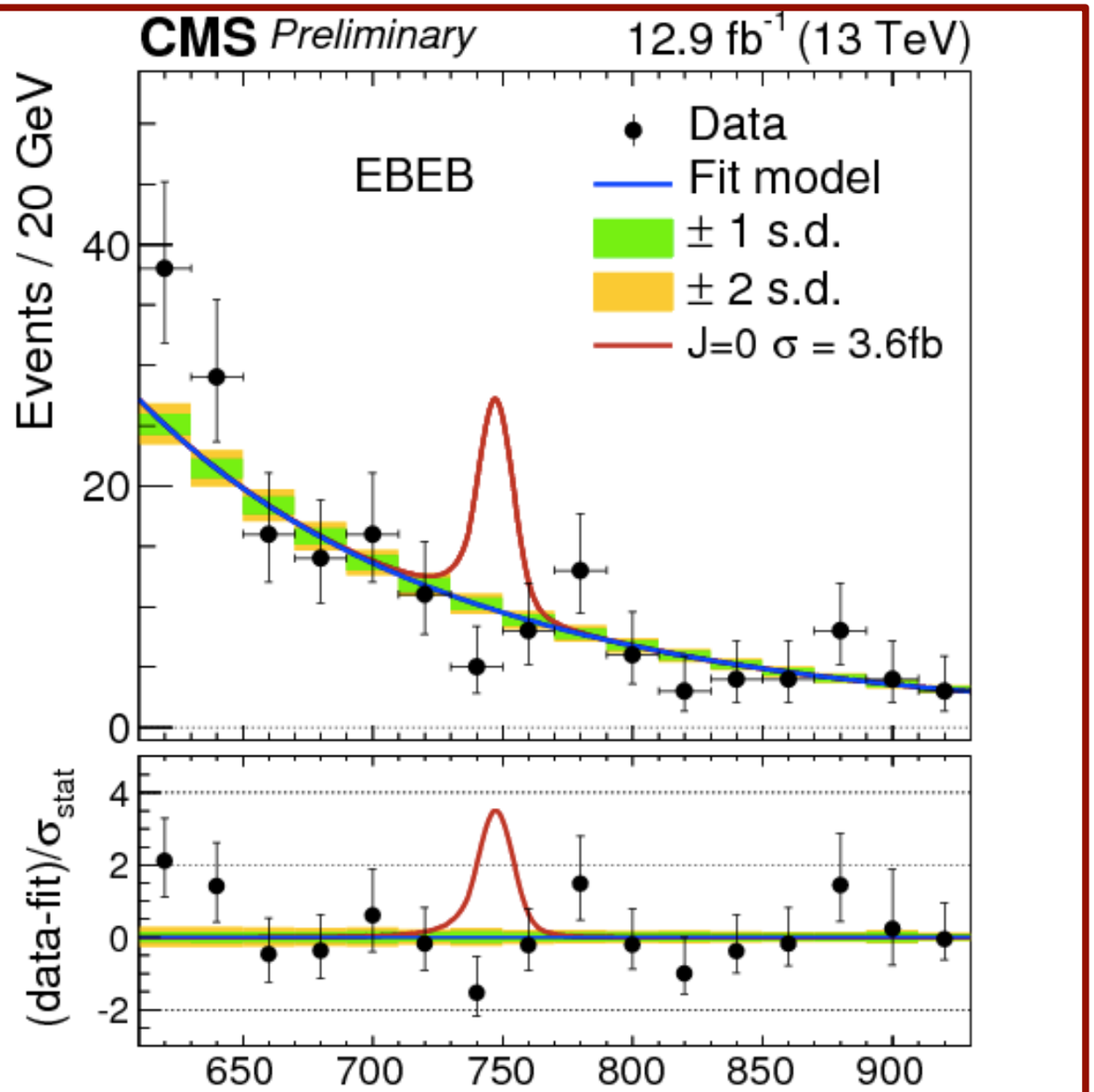
Di-photon: at 750 GeV

- What is seen now

CMS PAS EXO-16-027

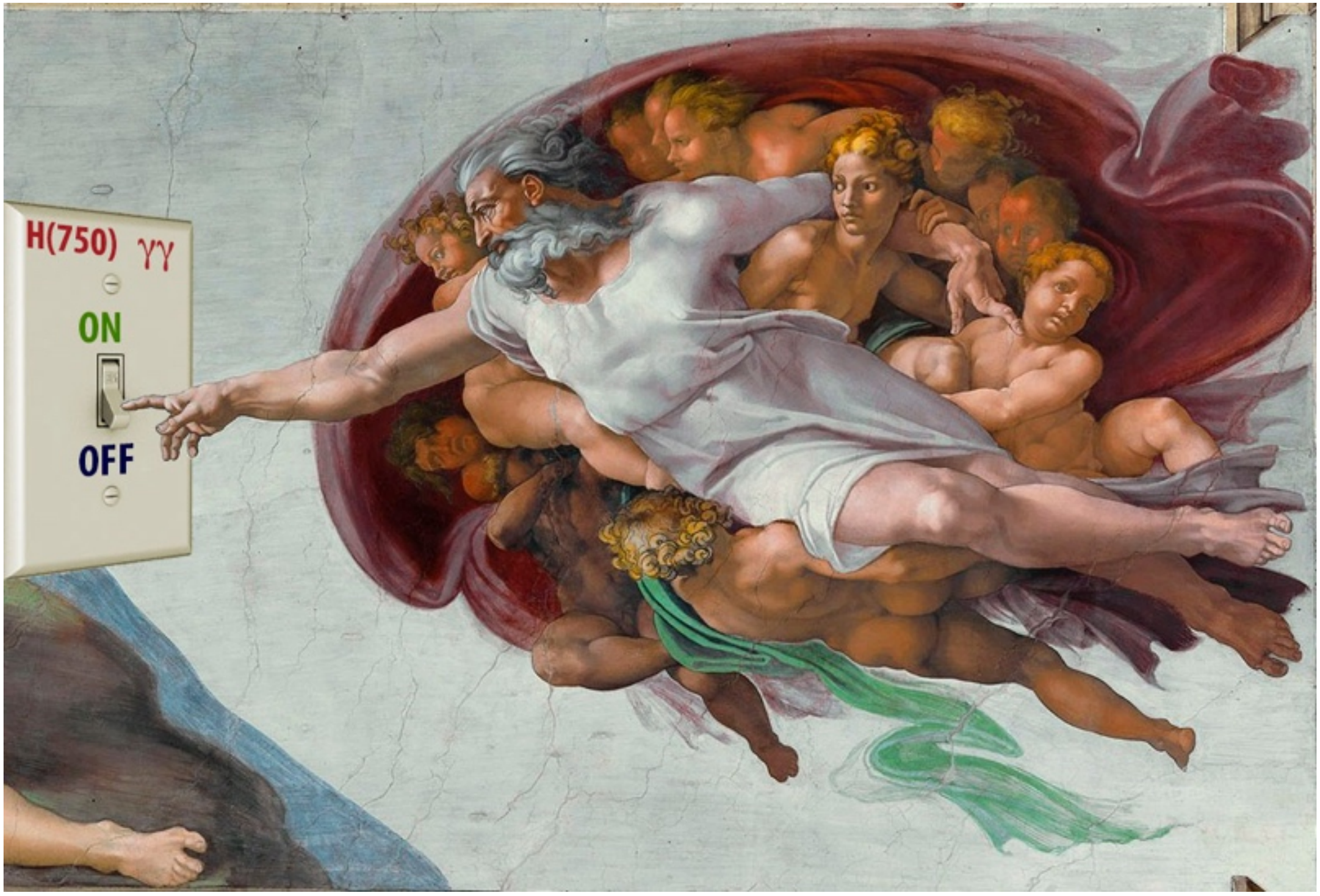


- What we would have seen



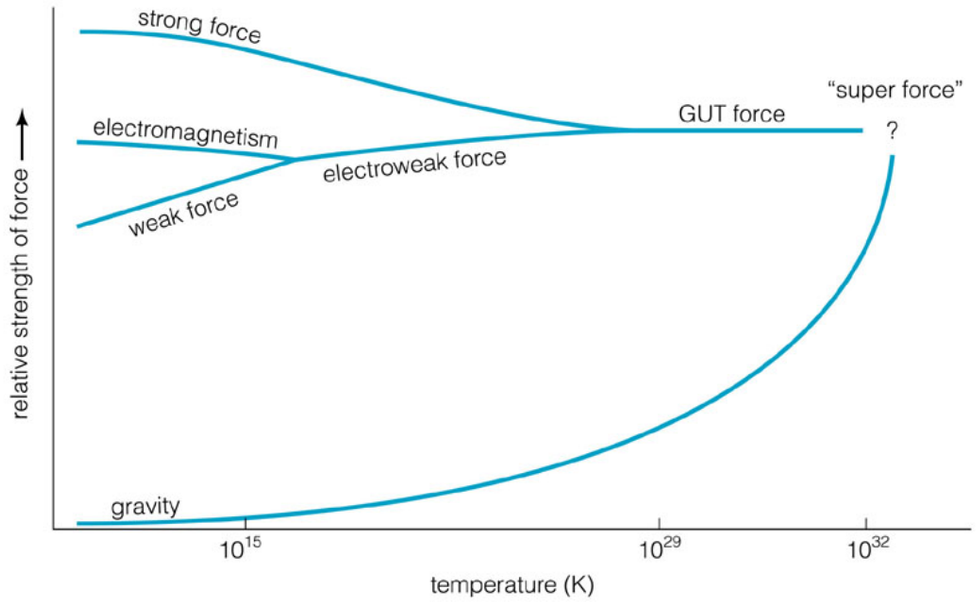
It's gone from ATLAS too ….

”...just to mess with phenomenologists…”



Dilepton Resonance

- Very clean signature
  - high signal efficiencies and small well-understood backgrounds.



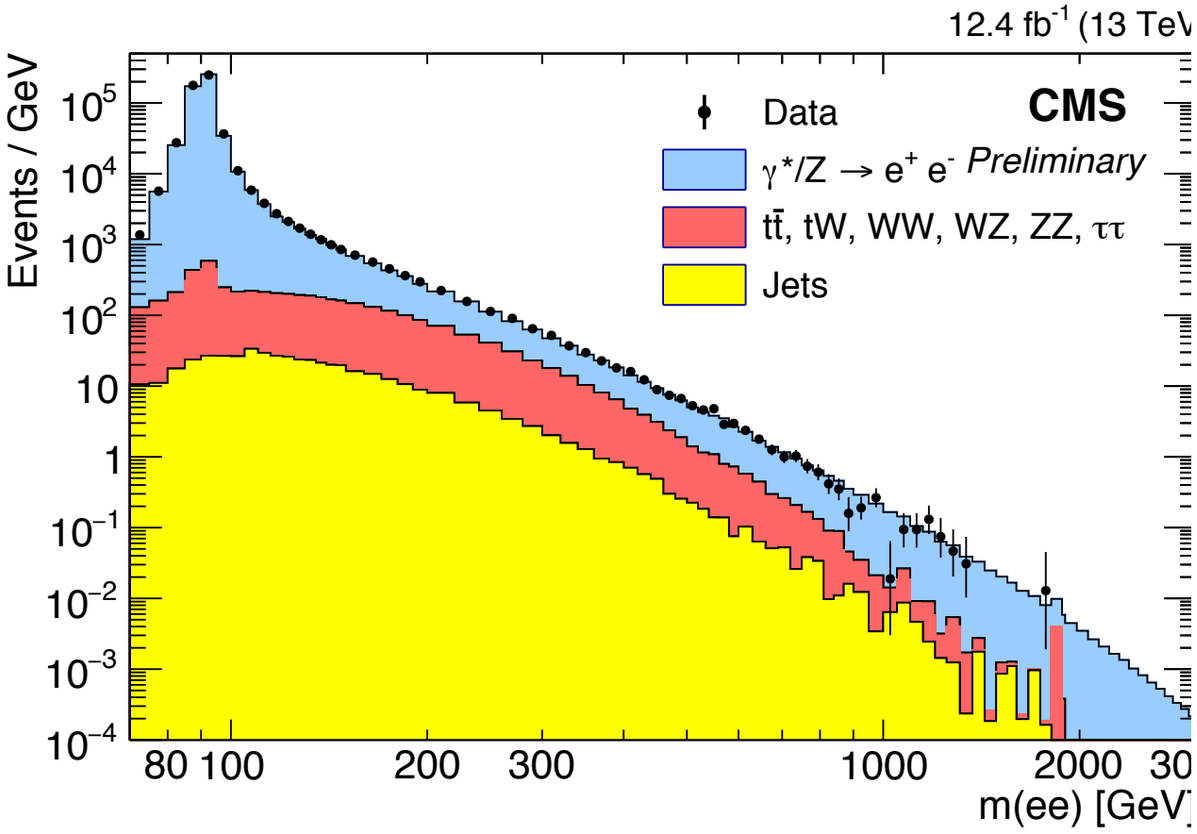
- GUT Theories
  - Fundamental interactions have common root ?
  - Maybe strong and electroweak interactions are described by one, larger, gauge group at $E > E_{GUT}$.
    - At $E<E_{GUT}$ the group breaks into SM groups.

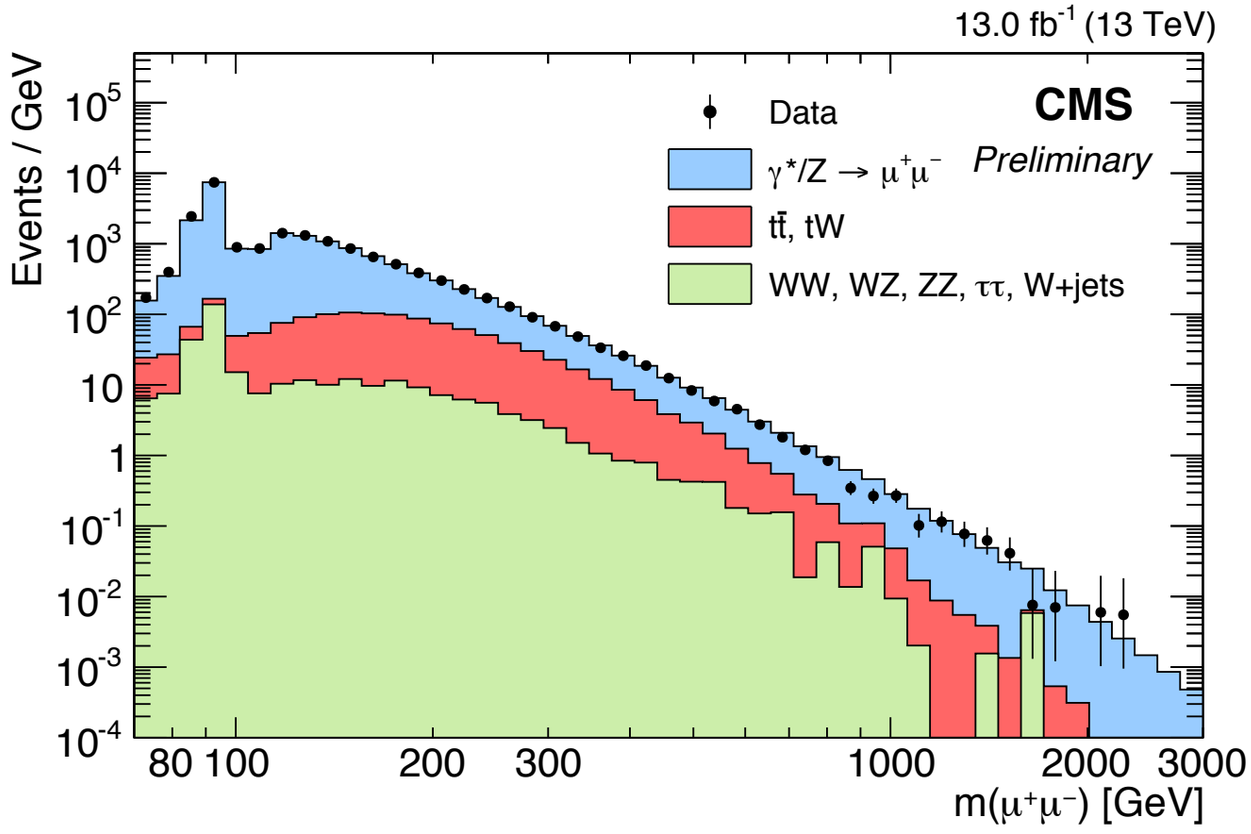
- Many of these models predict, at TeV scale, additional neutral gauge bosons, interacting similarly to the Z^0

Dilepton Resonance

CMS EXO-16-031

- Separate by flavor: ee and μμ



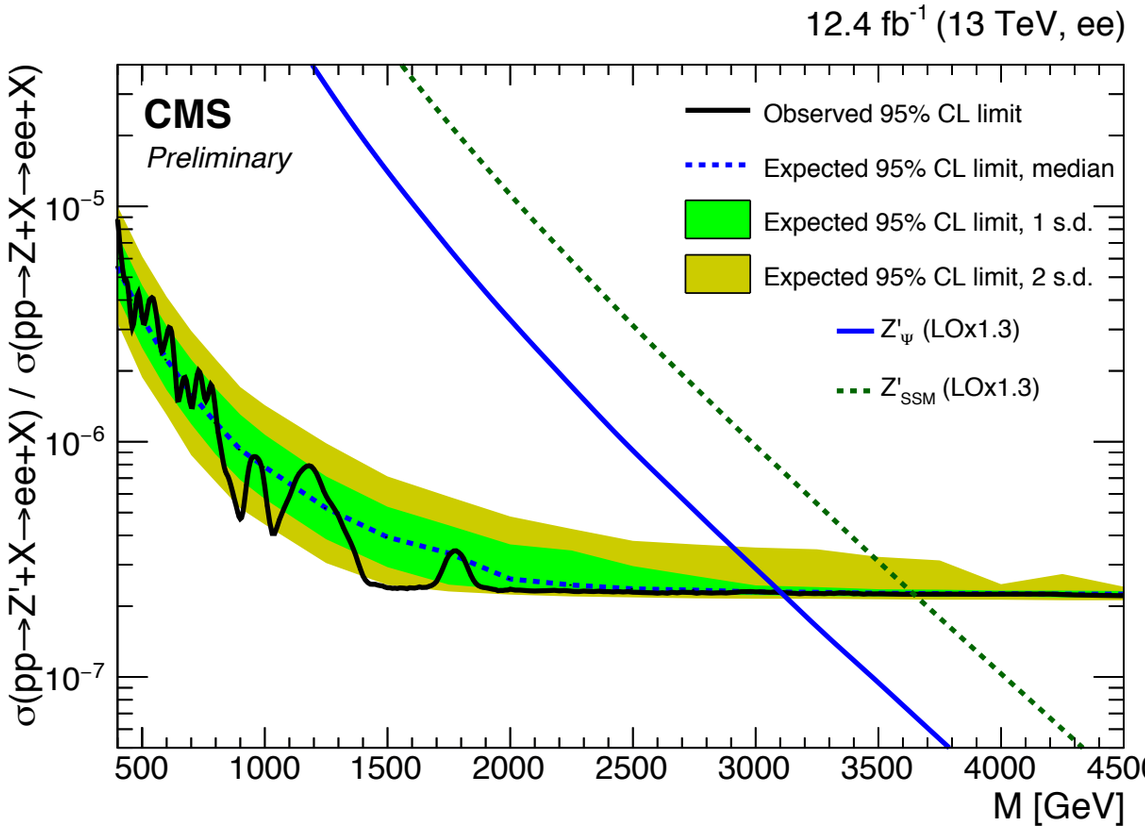


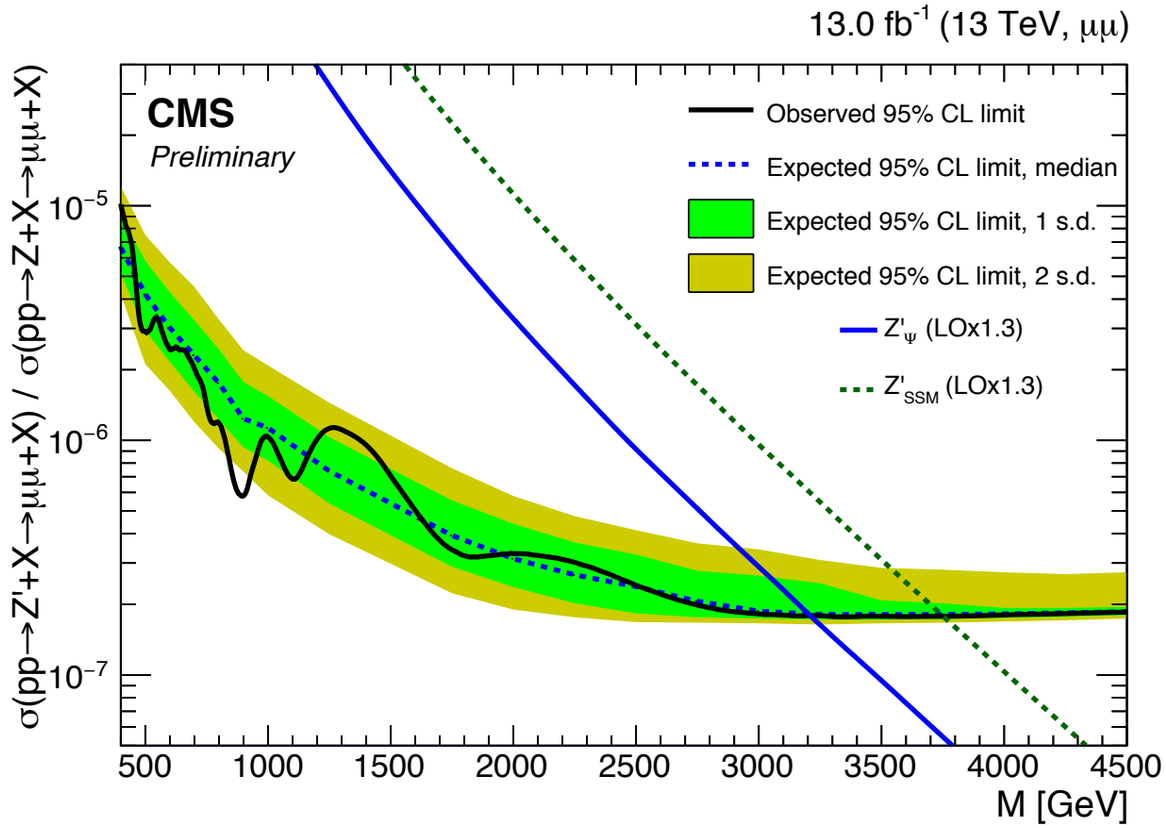
Agreement over 6 orders of magnitude !!

Dilepton Resonance

CMS EXO-16-031

- Separating by flavor: ee and μμ





Exclude $M_{Z'}$ up to 3.65 TeV

Exclude $M_{Z'}$ up to 3.75 TeV

Limits valid for narrow resonances ($\Gamma \sim 0.02 m_X$), assume on-shell cross sections and do not include interference effects

Higgs

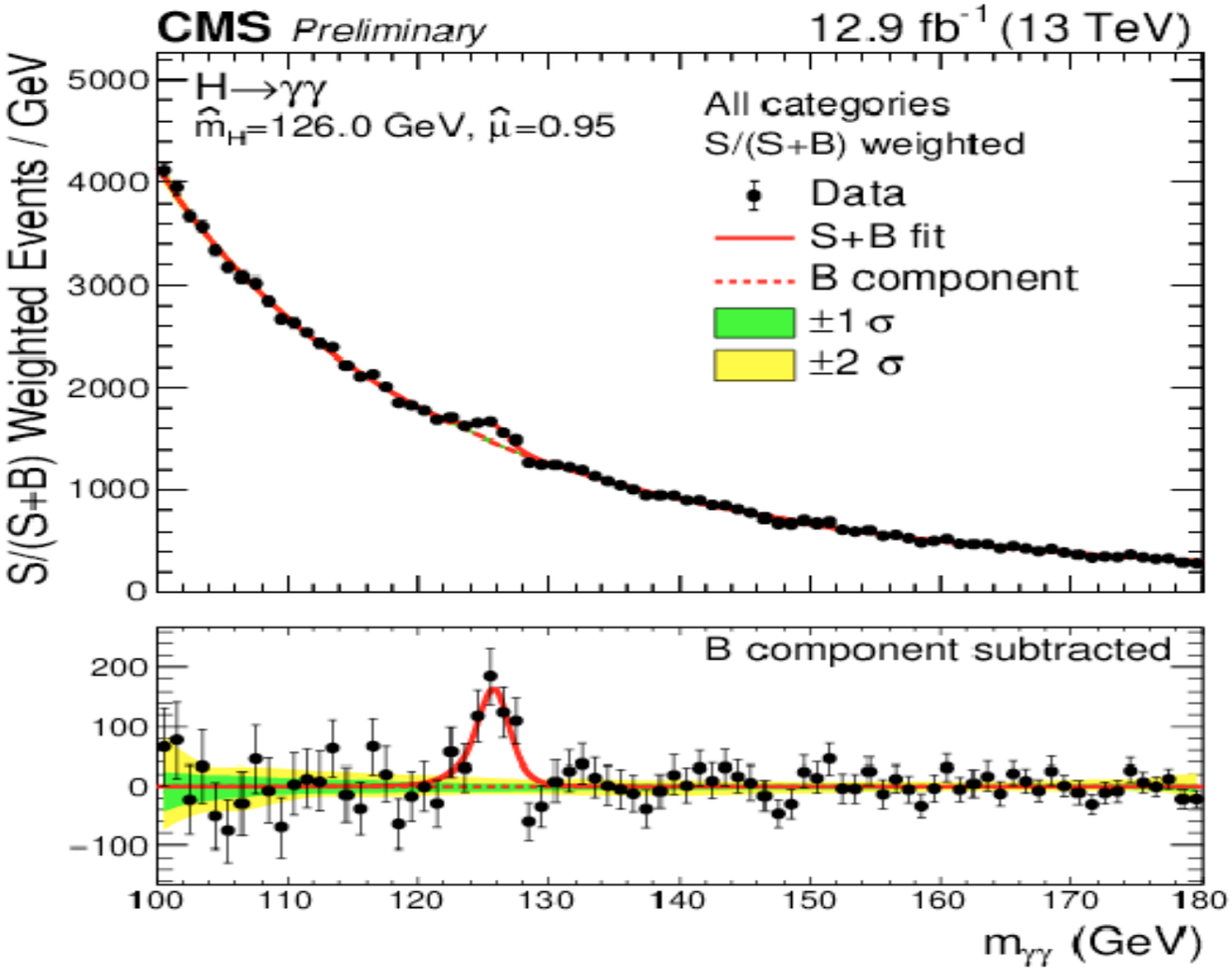
Some new Higgs analyses for ICHEP 2016

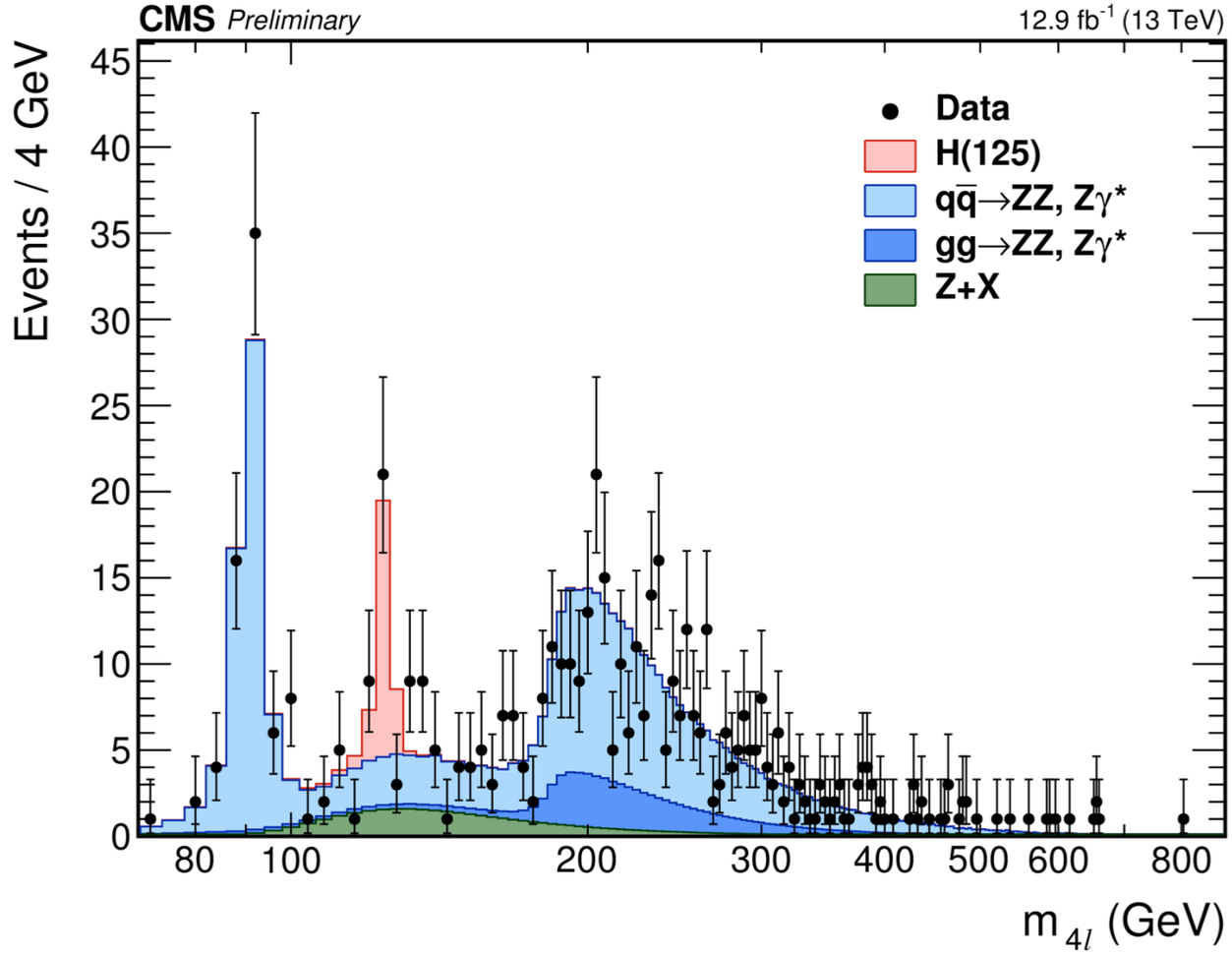
HIG-16-019	*Search for H→bb¯ in association with a single top quark as a test of Higgs boson couplings at sV= 13 TeV*
HIG-16-020	*Higgs to gammagamma measurements at 13 TeV using 2016 data*
HIG-16-022	*Search for the ttH process with multilepton decays using the 2016 data*
HIG-16-023	*Search for high mass Higgs to WW with fully leptonic decays using 2015 data*
HIG-16-024	*Search for the nonresonant HH process with WWbb decays using 2015 data*
HIG-16-025	*Search for a heavy Higgs boson decaying to bottom quark pairs in the 13 TeV data sample*
HIG-16-027	*Search for charged Higgs bosons in WZ decays at 13 TeV*
HIG-16-028	*Search for H(bb)H(tautau) decays from non-resonant production*
HIG-16-029	*Search for H(bb)H(tautau) decays from resonant production*
HIG-16-033	*Higgs to four leptons measurements at 13 TeV with 2016 data*

Higgs “Rediscovery”

➢H→ɣɣ | CMS HIG-16-020

➢H→ZZ→4 leptons | CMS HIG-16-033



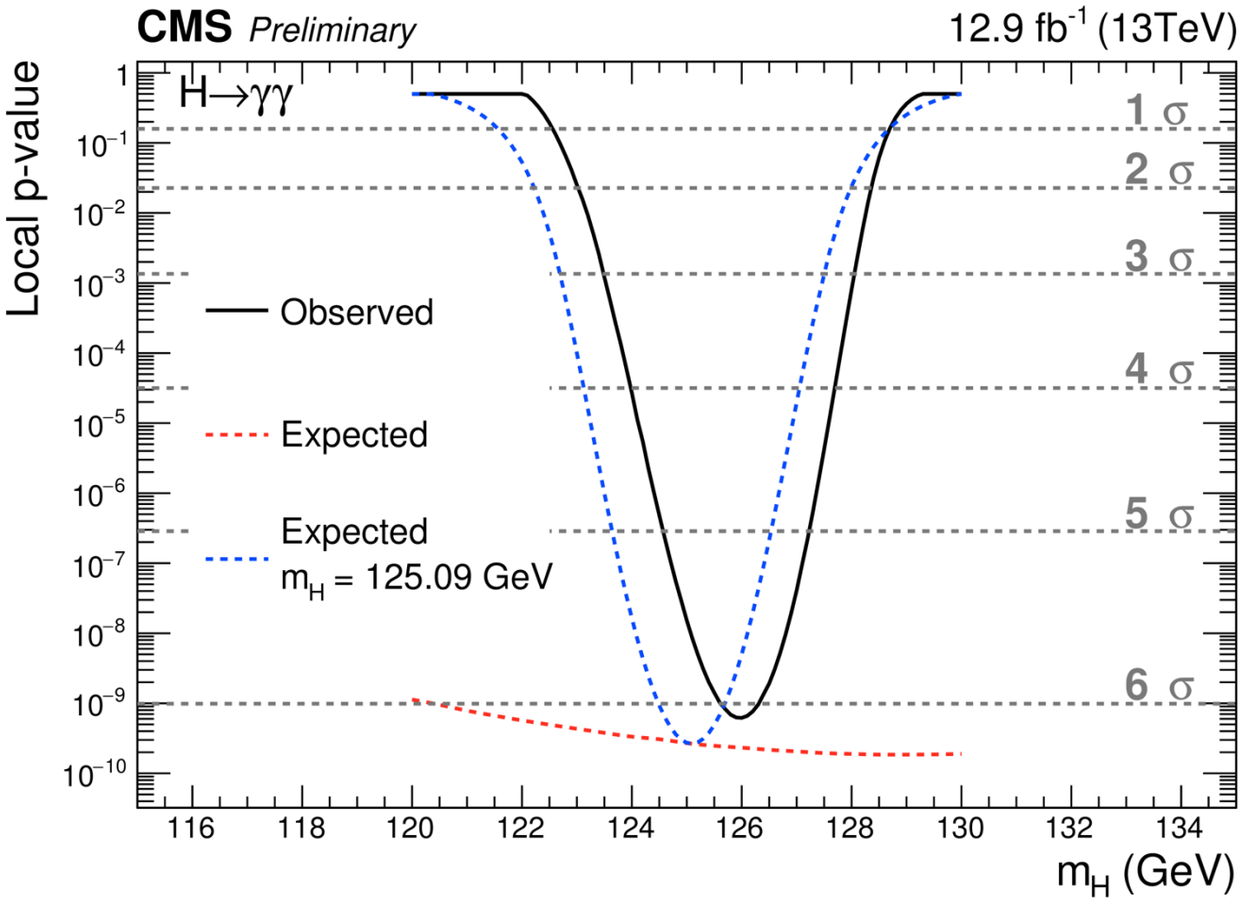


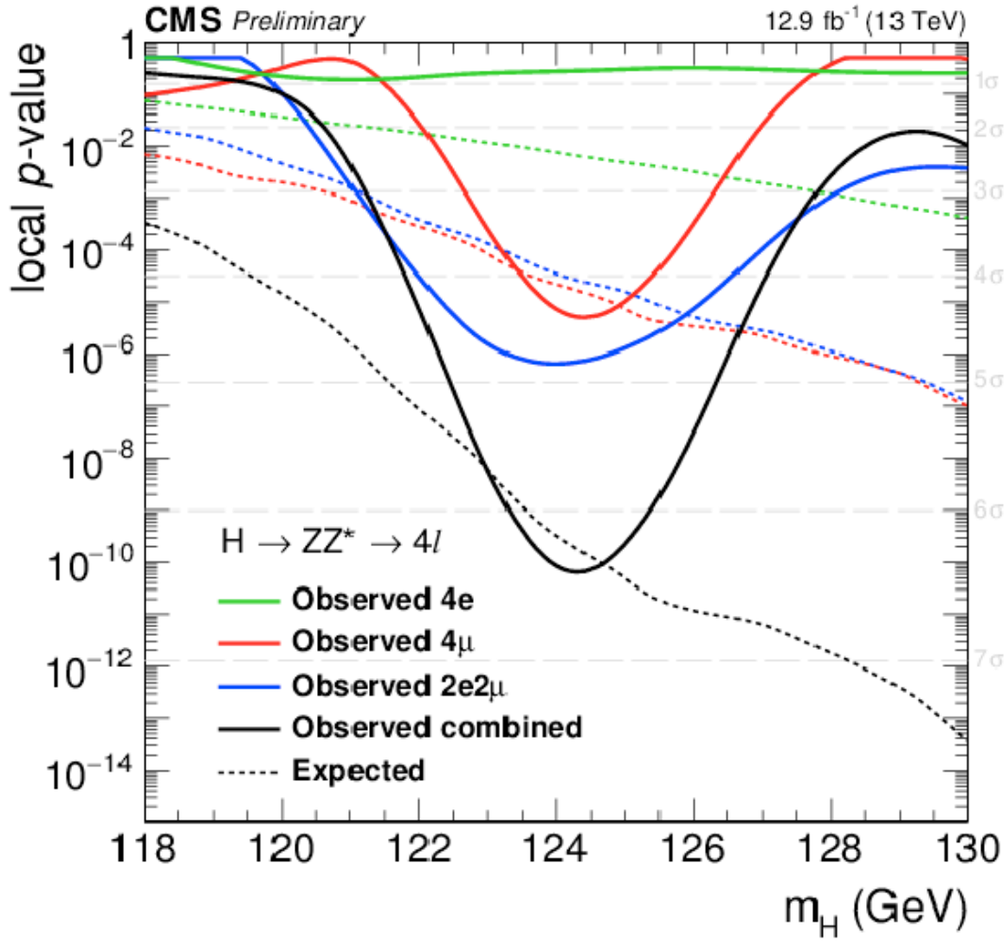
Signal clear to the naked eye

Higgs “Rediscovery”

➢H→ɣɣ | CMS HIG-16-020

➢H→ZZ→4 leptons | CMS HIG-16-033





Well beyond 5 sigma in each independent channel.

Higgs properties from H→ZZ→4 leptons

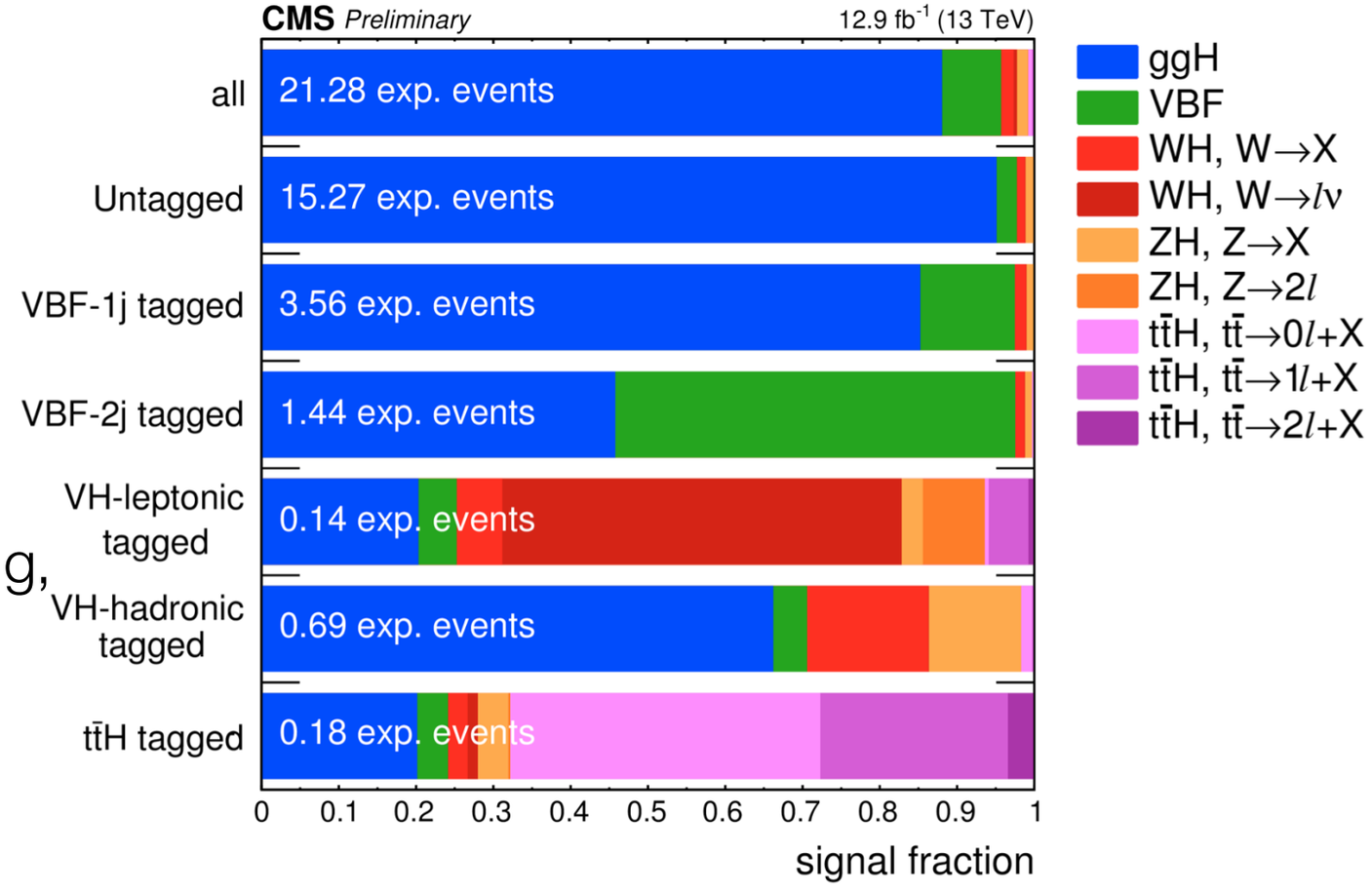
CMS HIG-16-033

Channel well suited for understanding Higgs properties:

- Large signal to background ratio channel
- Complete reconstruction of final state decay products
- Excellent lepton momentum resolution

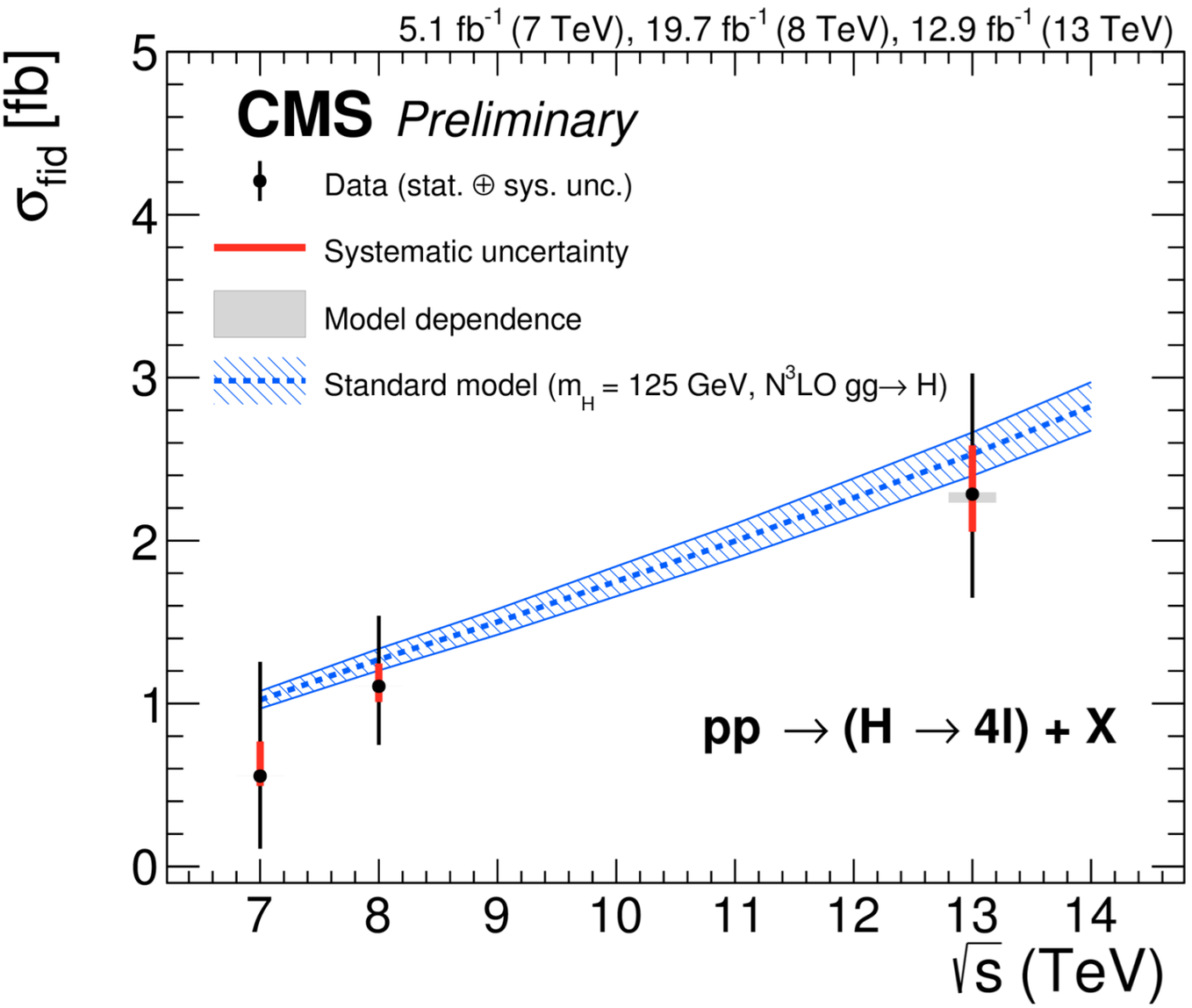
<u>In a nutshell:</u>

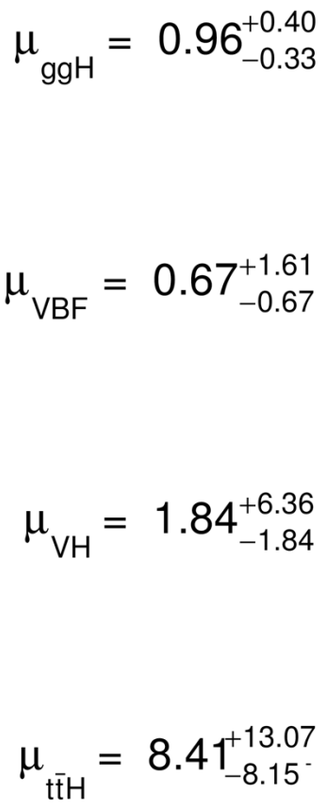
- Form Z candidate from leptons:
  - same flavor, opposite charge, within some Z window.
- Combine into ZZ : 4e, 4μ, 2e2μ
  - Place several safety requirements on Z candidates and ZZ events (e.g, m_{ll}>4 for all lepton combinations)
- Separate in 6 exclusive "categories" :
  - Total of 18 = 3 x 6 bins.

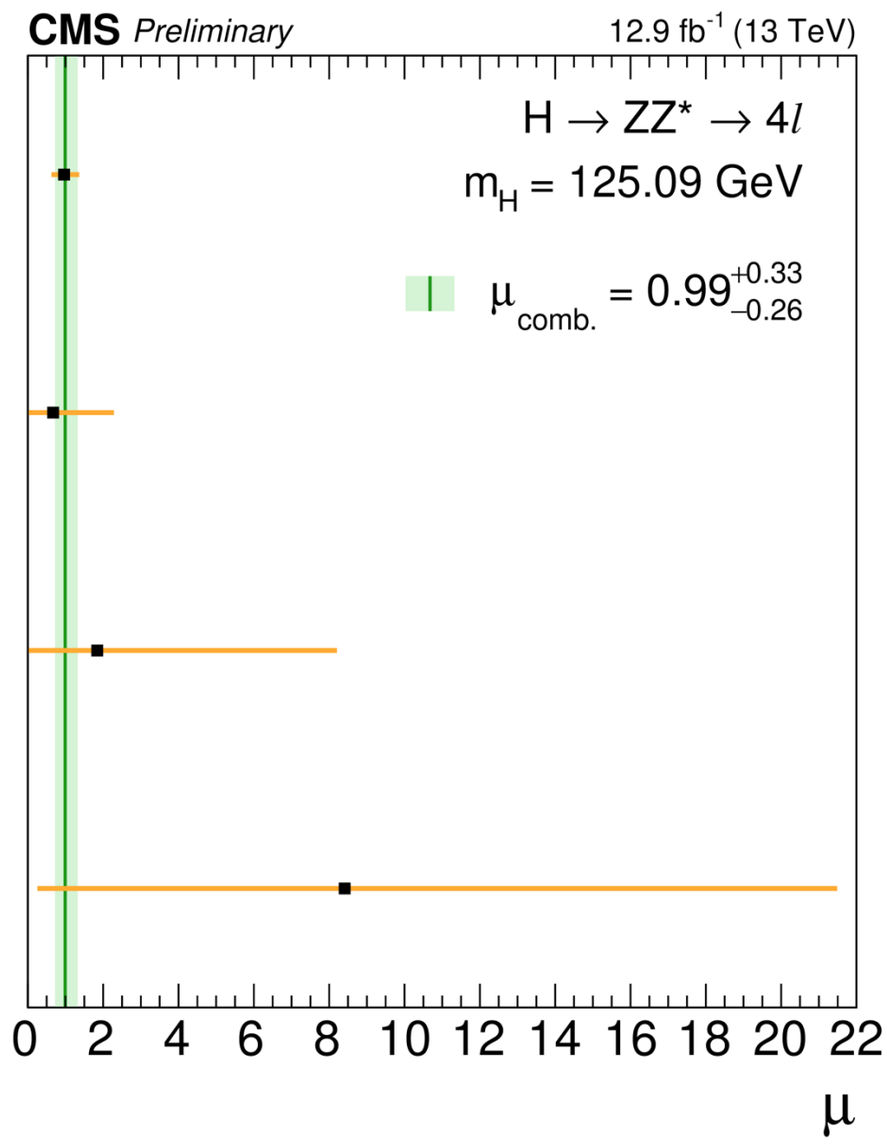


Higgs properties from H→ZZ→4 lep: XS

CMS HIG-16-033



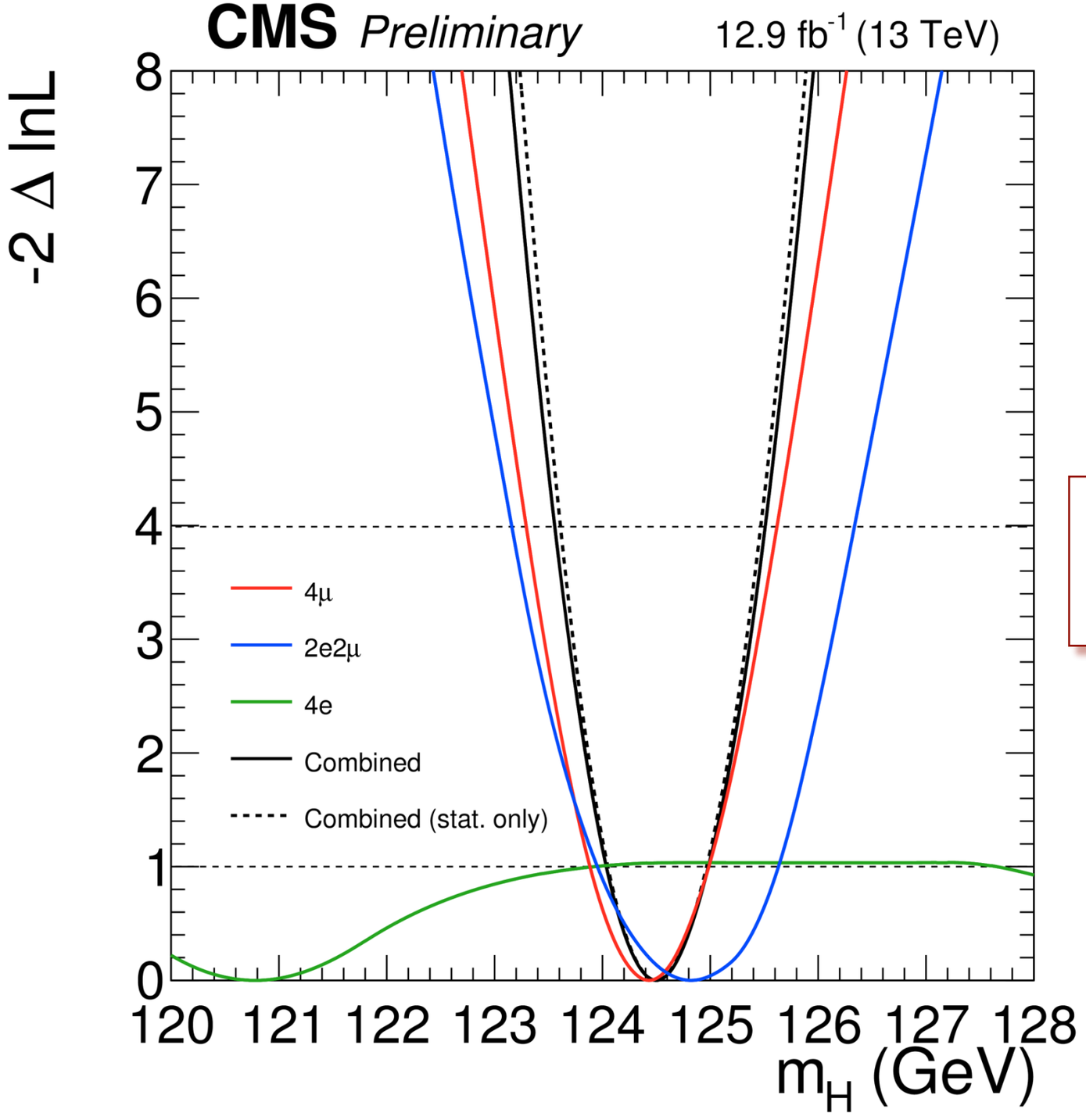




Cross section compatible with SM.
No tension in signal strength between all channels.

Higgs properties from H→ZZ→4 lep: Mass

CMS HIG-16-033



$$m_{\mathrm{H}} = 124.50^{+0.48}_{-0.46}\ \mathrm{GeV}$$

Higgs properties from H→ZZ→4 lep: Width

- Measured cross sections can be kept fixed if one simultaneously rescales couplings of the Higgs boson to SM particles and the Higgs boson width by appropriate factors.

PRD 88, 054024 (2013)

- In the peak region we measure cross section

$$\sigma_{i\to H\to f} \sim \frac{g_i^2 g_f^2}{\Gamma_H}$$

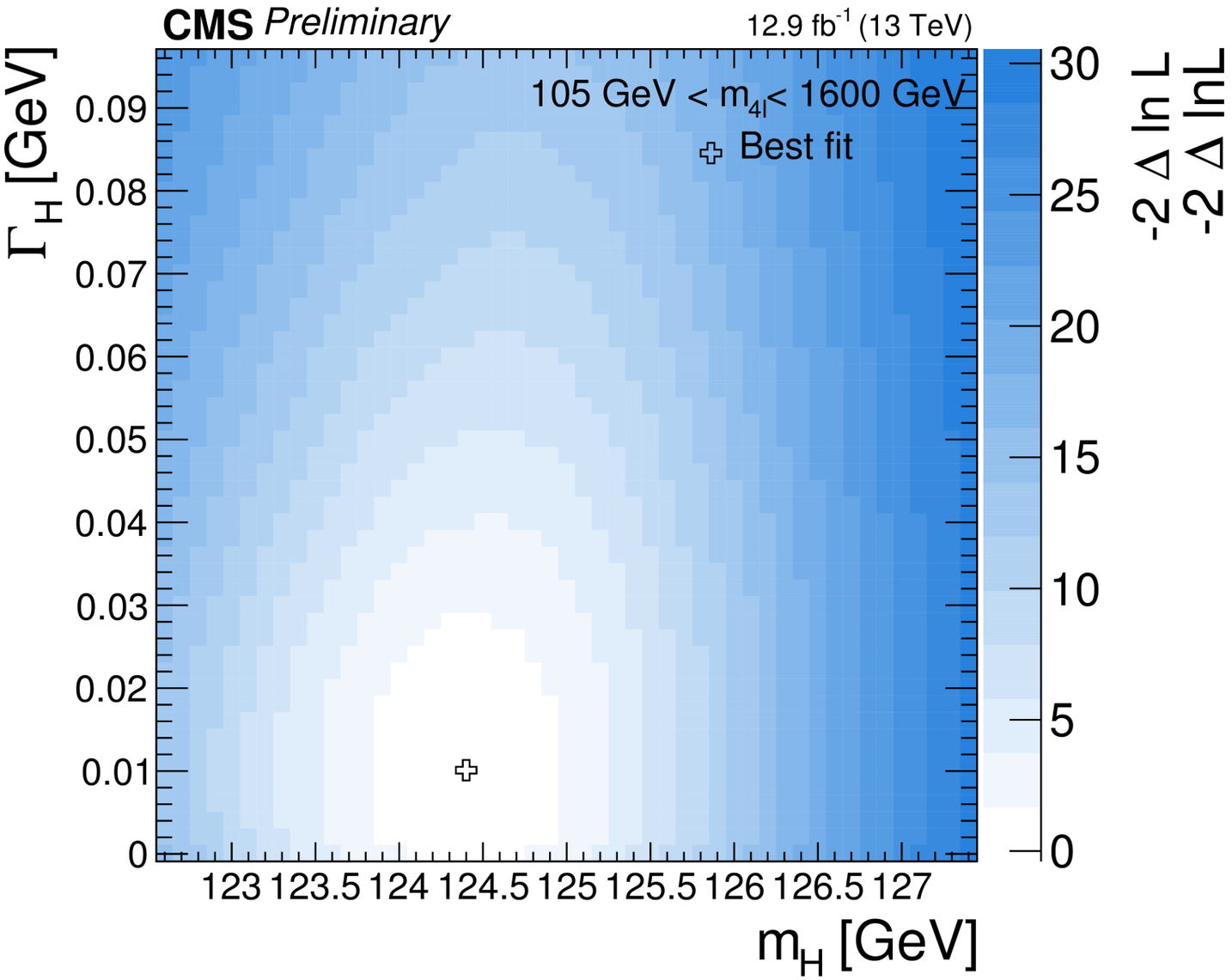
remains the same with simultaneous rescaling of product of couplings^2 and width.

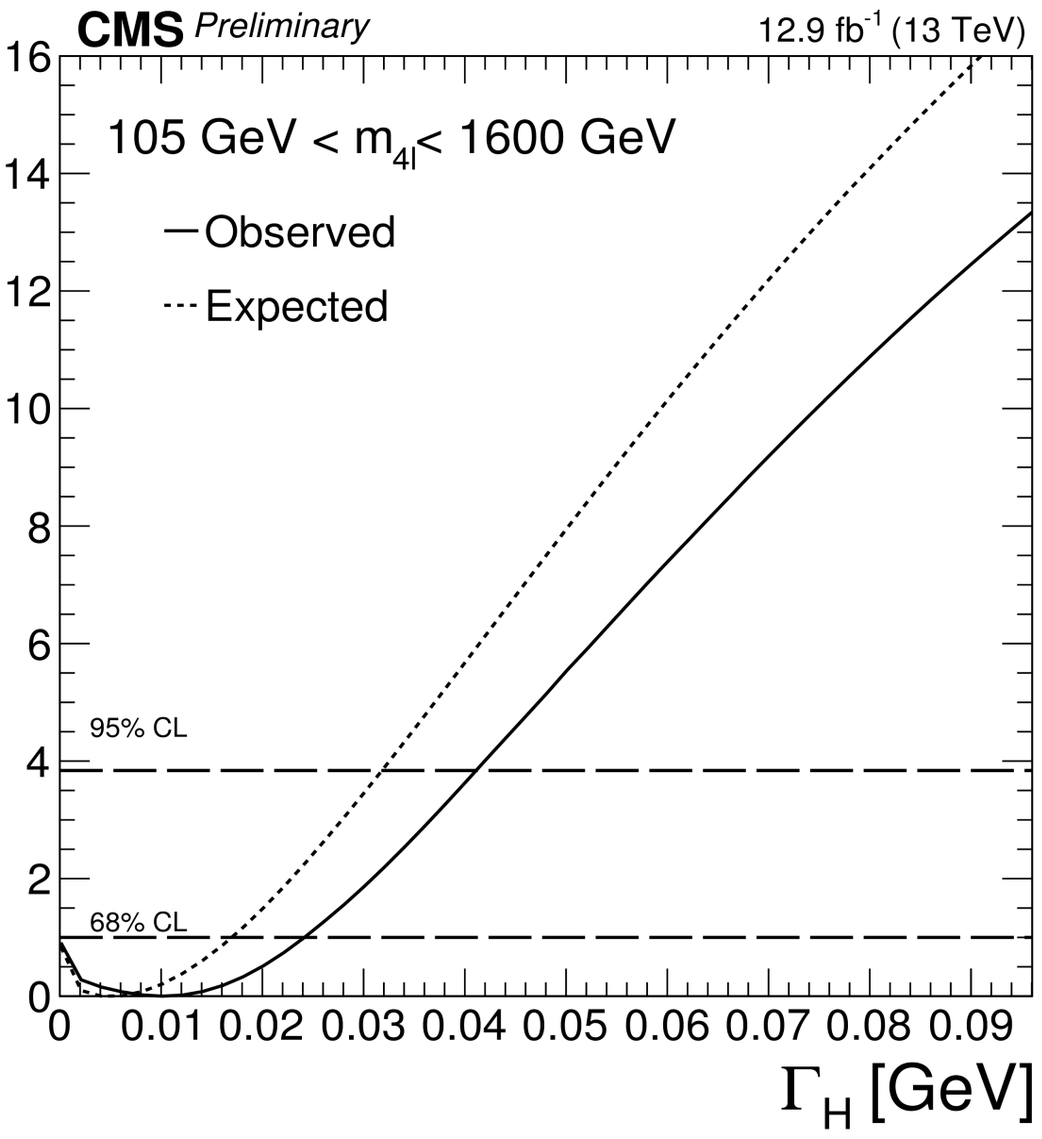
- Production of off-shell Higgs' is independent of the width and changes proportionally to rescaling of the product of couplings^2

- Use this to measure absolute width.

Higgs properties from H→ZZ→4 lep: Width

CMS HIG-16-033

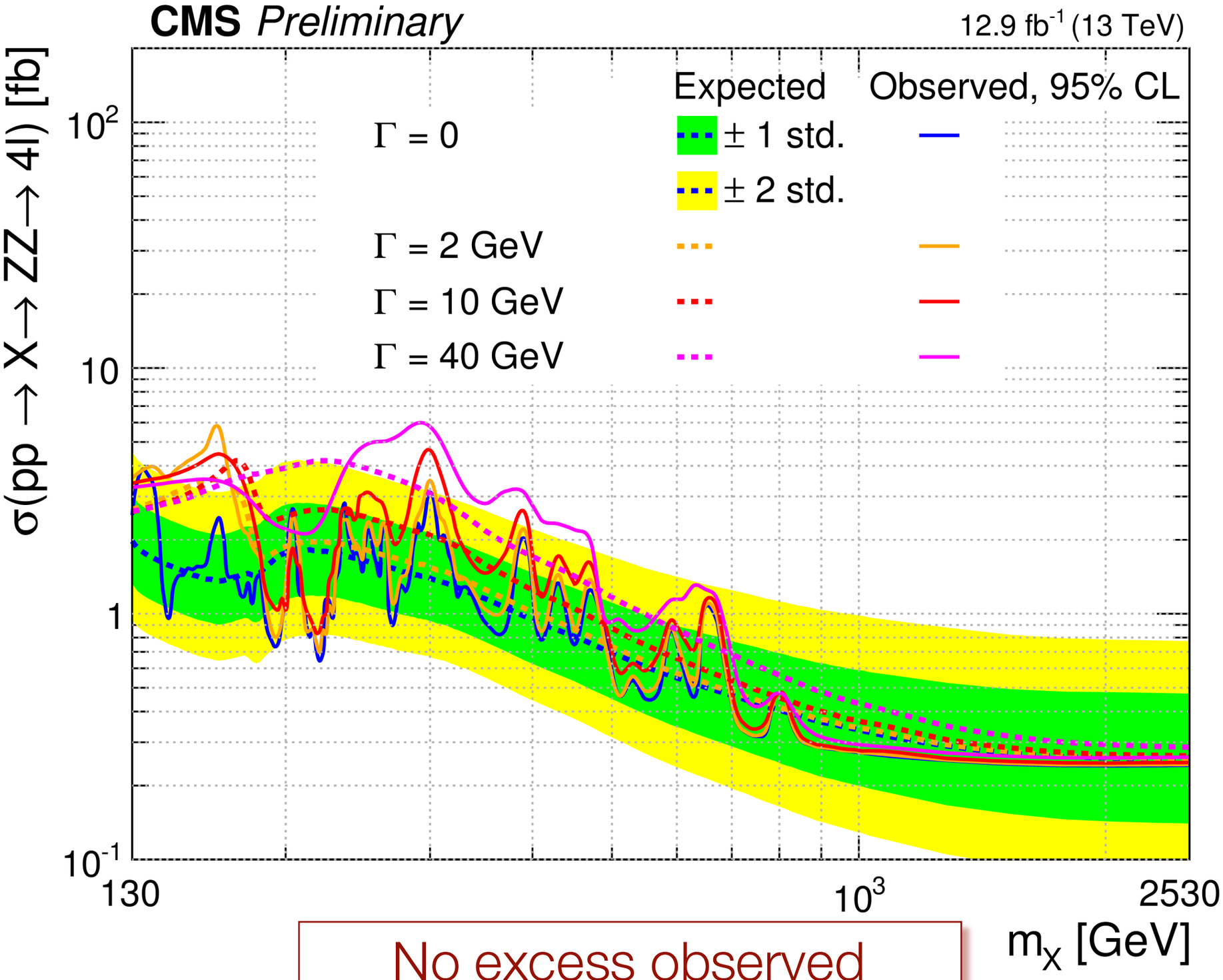




Width of Higgs constrained to be less than 41 MeV at 95% CL.
(compared to 3.9 GeV is considering only on-shell production)

Resonance pp→X→ZZ→4 leptons

CMS HIG-16-033



No excess observed

Dark Matter Searches

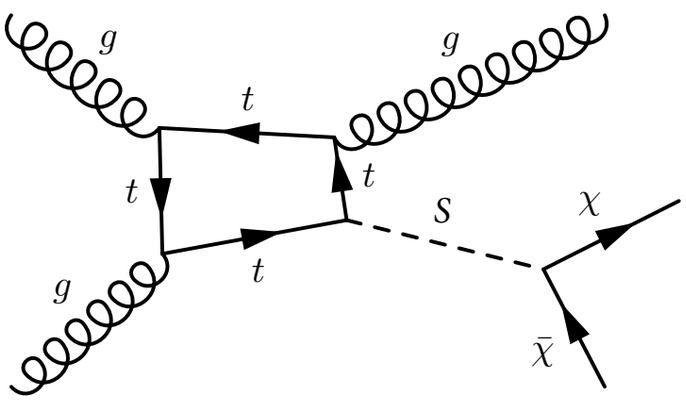
Some new Dark Matter analyses for ICHEP 2016

EXO-16-005	*Search for dark matter in association with a top quark pair at sV= 13 TeV*
EXO-16-010	*Search for dark matter and unparticles in events with a Z boson and missing transverse momentum in proton-proton collisions at sV= 13 TeV*
EXO-16-011	*Search for dark matter produced in association with a Higgs boson decaying to two photons*
EXO-16-022	*Search for displaced leptons at 13 TeV (e-mu channel)*
EXO-16-037	*Search for dark matter in jets+MET final state with 2016 data*
EXO-16-038	*Search for dark matter in Z(ll) MET final state using the 2016 dataset*
EXO-16-039	*Search for dark matter in photon+MET final state with 2016 data*
EXO-16-040	*Search for dark matter in top+MET final state with 2016 data*
EXO-16-043	*Search for pair production of first generation leptoquarks*

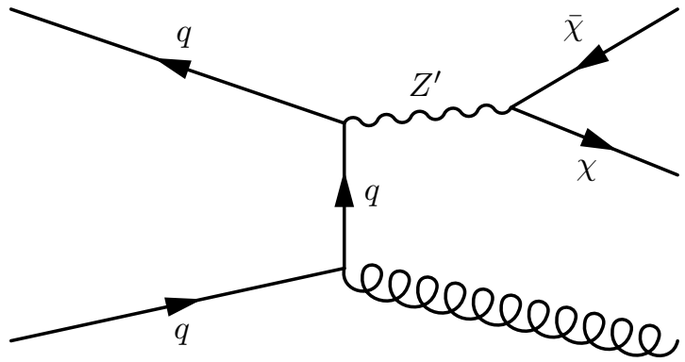
Dark Matter

- No experimental evidence of Dark Matter non-gravitational interaction with SM particles.
  - If DM and SM particles interact, then DM can be produced in proton-proton collisions
- In many models, DM interact via mediators:

Scalar Mediator



Vector Mediator

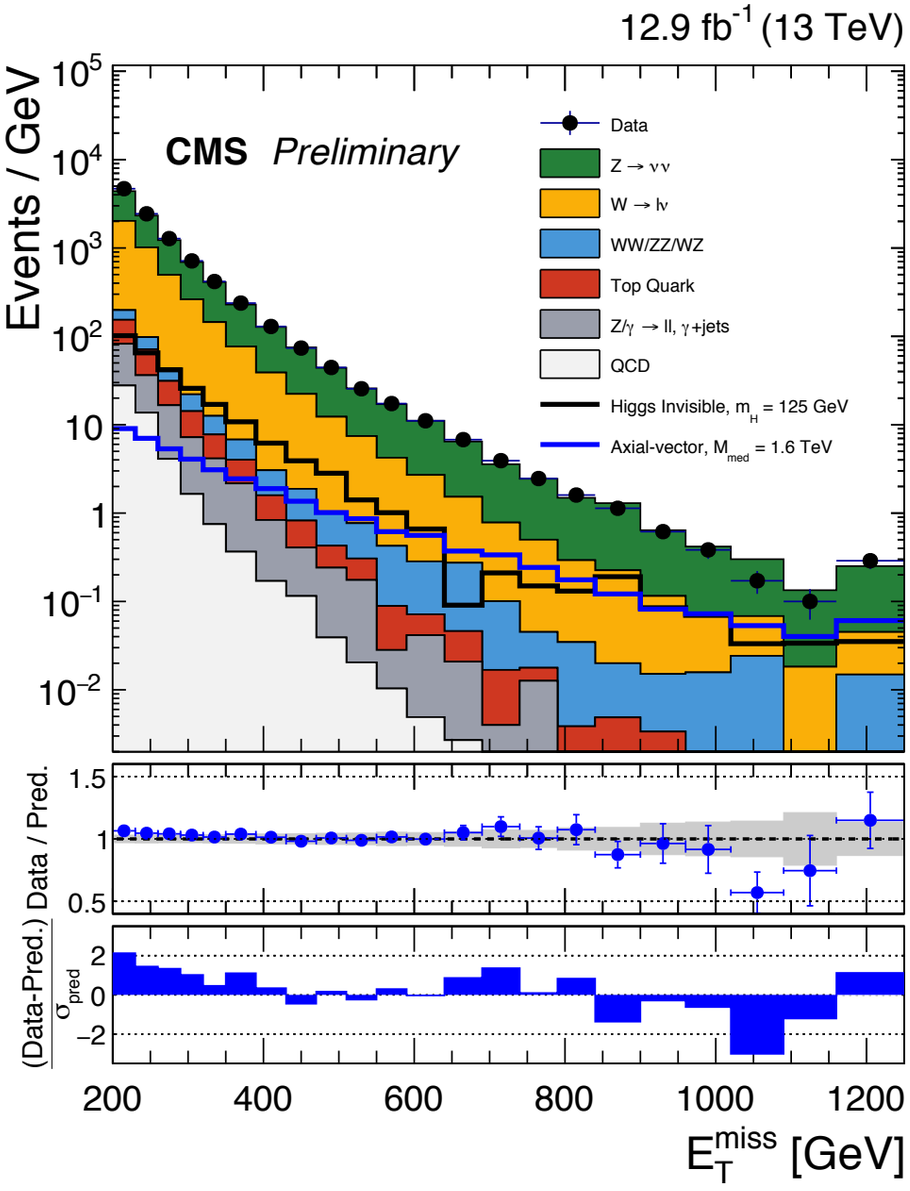


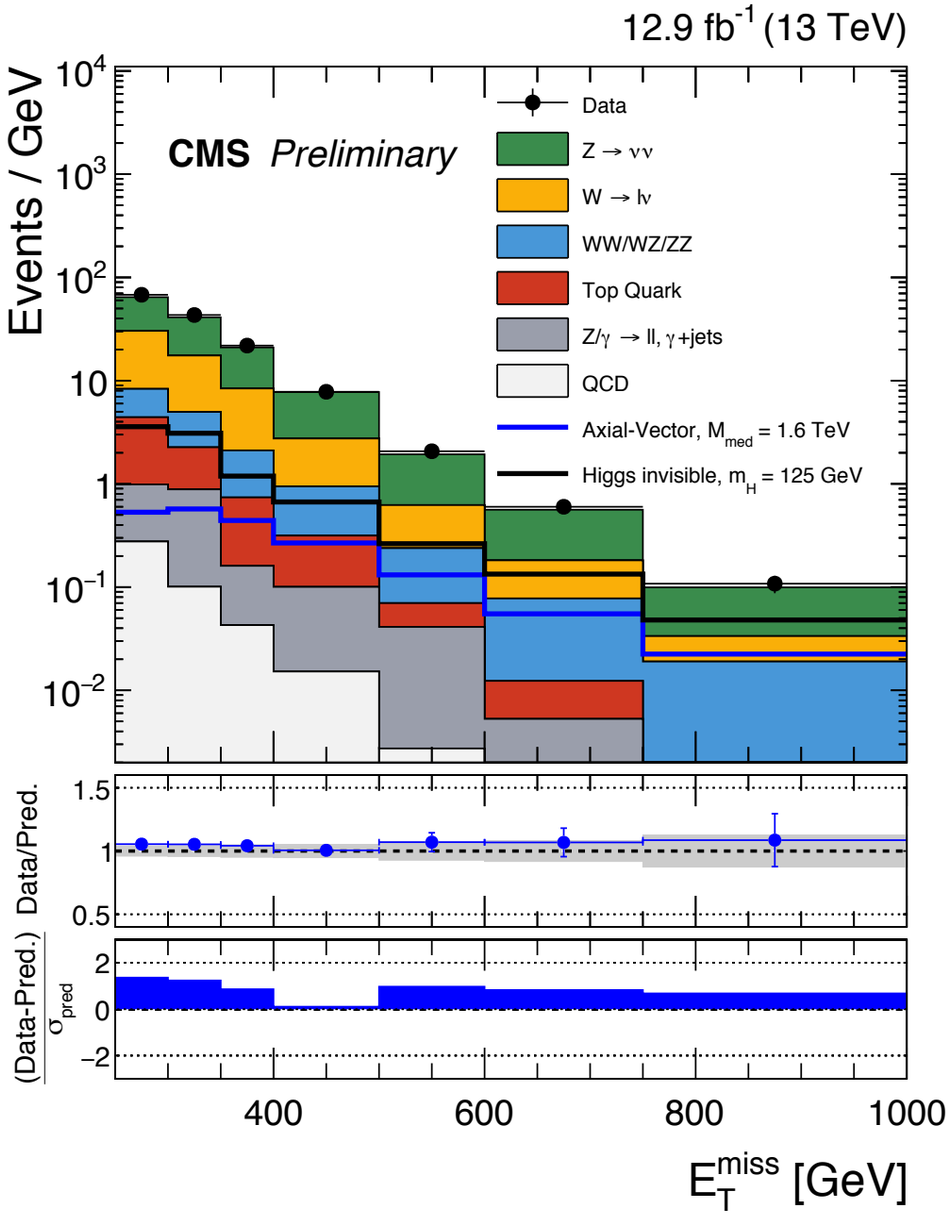
Striking signature of a single object with large momentum imbalance
"Mono-X" searches, where X=jet, photon, lepton, W, Z,

Dark Matter: “Mono”-Jet & “Mono”-V

CMS EXO-16-037

- Search in the MET distribution for Mono-Jet and Mono-W/Z

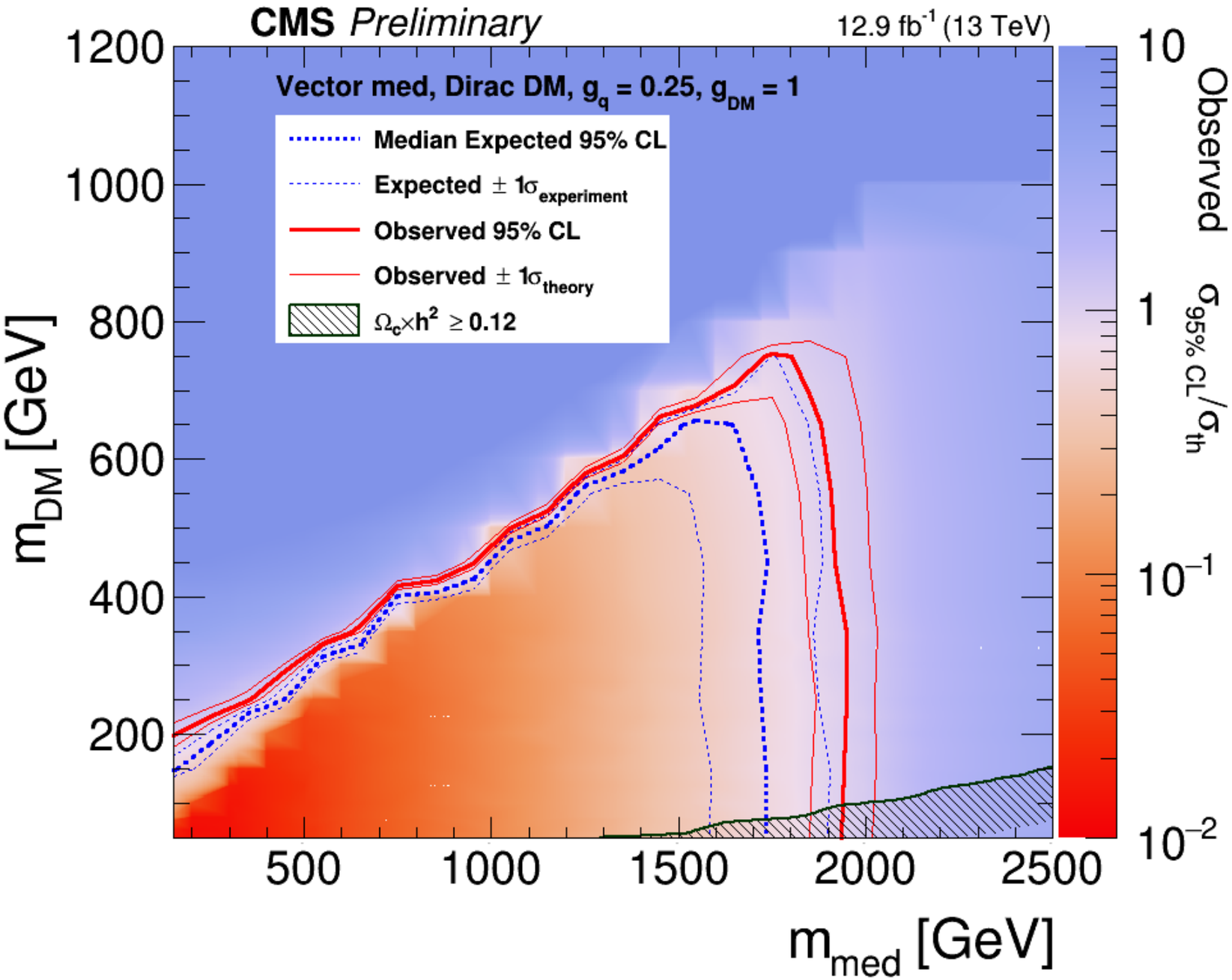




Use this to place limits on models

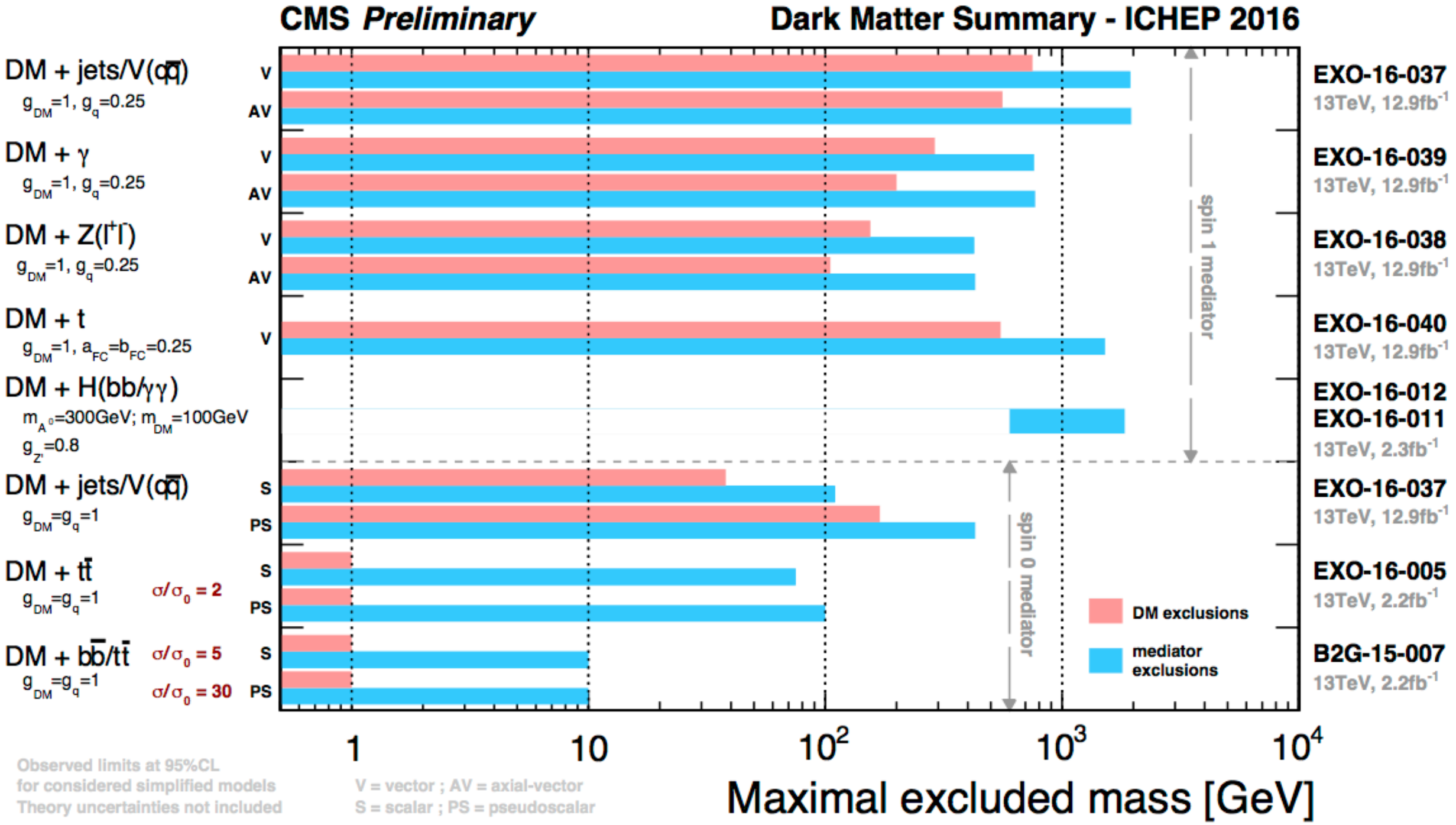
Dark Matter: Mono-Jet & Mono-V

CMS EXO-16-037



Limits on plane of mass-DM vs mass-mediator.
For Vector mediator exclude m_{med}<1.95 TeV and m_{DM}<770 GeV

Dark Matter: Summary



SUSY searches

Some new SUSY analyses for ICHEP 2016

SUS-16-012	*Search for SUSY in Events with a Higgs Decaying to Two Photons Using the Razor Variables*
SUS-16-013	*Search for RPV SUSY in 0l and 1l final states*
SUS-16-014	*Search for supersymmetry in the multijet and missing transverse momentum channel in pp collisions at 13 TeV (RA2/b)*
SUS-16-015	*Search for new physics in the all-hadronic final state with the MT2 variable (MT2)*
SUS-16-016	*Search for new physics in final states with jets and missing transverse momentum in sqrt(s) = 13 TeV pp collisions with the alpha_T variable (AlphaT)*
SUS-16-019	*Search for supersymmetry in events with one lepton (1l dphi)*
SUS-16-020	*Search for SUSY in same-sign dilepton events at 13 TeV (SS2l)*
SUS-16-021	*Search for SUSY in final states with opposite-sign dileptons at 13 TeV (OS2l, strong + ewk production)*
SUS-16-022	*Search for SUSY with multileptons in 13 TeV data (RA7)*
SUS-16-023	*Search for SUSY in photon + MET final states at 13 TeV*
SUS-16-024	*Search for electroweak SUSY production in multi-lepton final state at 13 TeV*
SUS-16-025	*Search for SUSY in the soft opposite-sign dilepton final state at 13 TeV (SOS)*
SUS-16-026	*Search for electroweak SUSY in the WH final state at 13 TeV*
SUS-16-028	*Search for direct top squark pair production in the single lepton final state at sV= 13 TeV*
SUS-16-029	*Search for direct stop pair production in the fully hadronic final state at 13 TeV*
SUS-16-030	*Search for SUSY with a customized top tagger at 13 TeV*

SUSY is around the corner

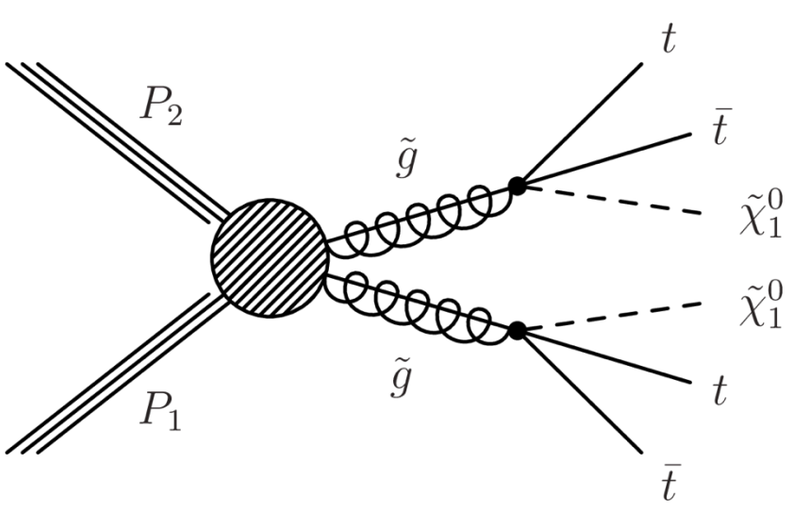
- Which one ?

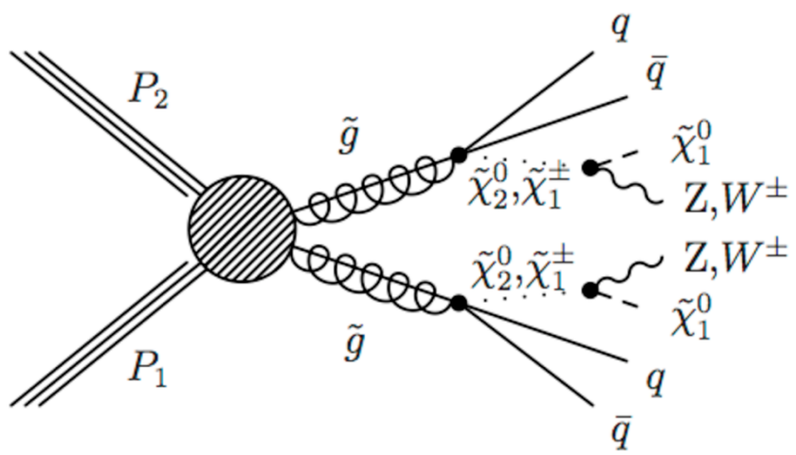
Targeted aim requires a bit of luck, broader searches not so much.

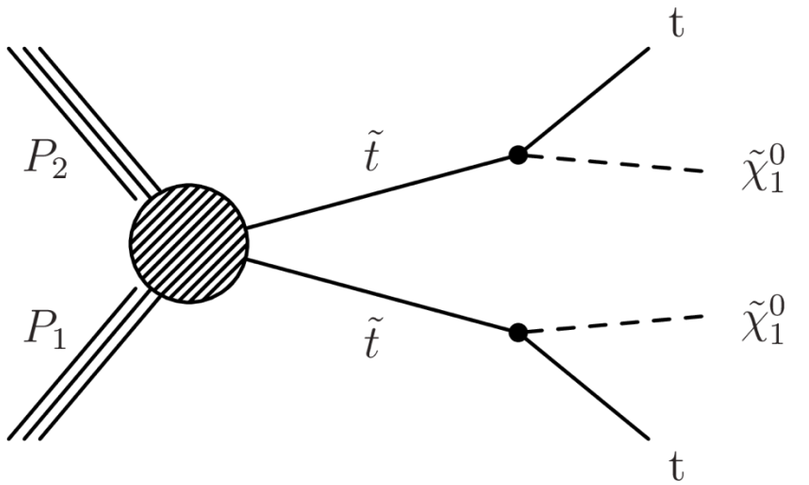
Search for SUSY in Jets+MET

CMS PAS SUS-16-014

- All hadronic search targeting several models







Models produce different signatures:

- Number of Jets
- Number of b-jets
- Missing Transverse Jet Momenta, MH_T
- Scalar sum of jet transverse momenta, H_T

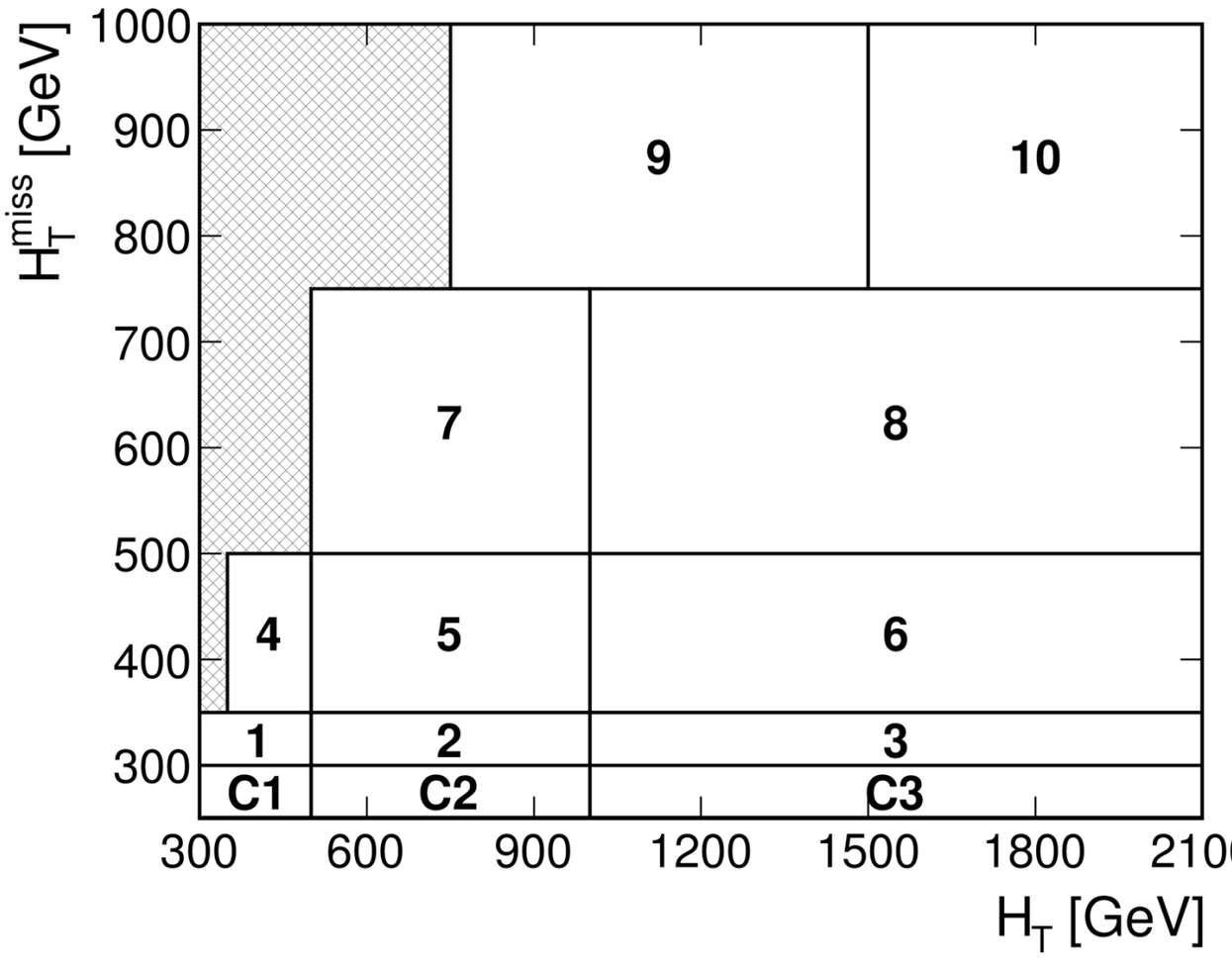
Search for SUSY in Jets+MET

CMS PAS SUS-16-014

Strategy in a nutshell

- Veto both isolated e or mu, and isolated tracks
- Require minimal $\Delta\Phi(MH_T,\text{jets})$ avoid MHT from mis-measured jets
- Split signal region into bins
  - **4 Njets bins**:
    [3-4,5-6,7-8, $\geqq$9]
  - **4 Nb-jets bins**:
    [0,1,2, $\geqq$3]
  - In each (Njet, Nbjet) bin **define 10** further different signal regions !

A total of **160** signal bins !!!

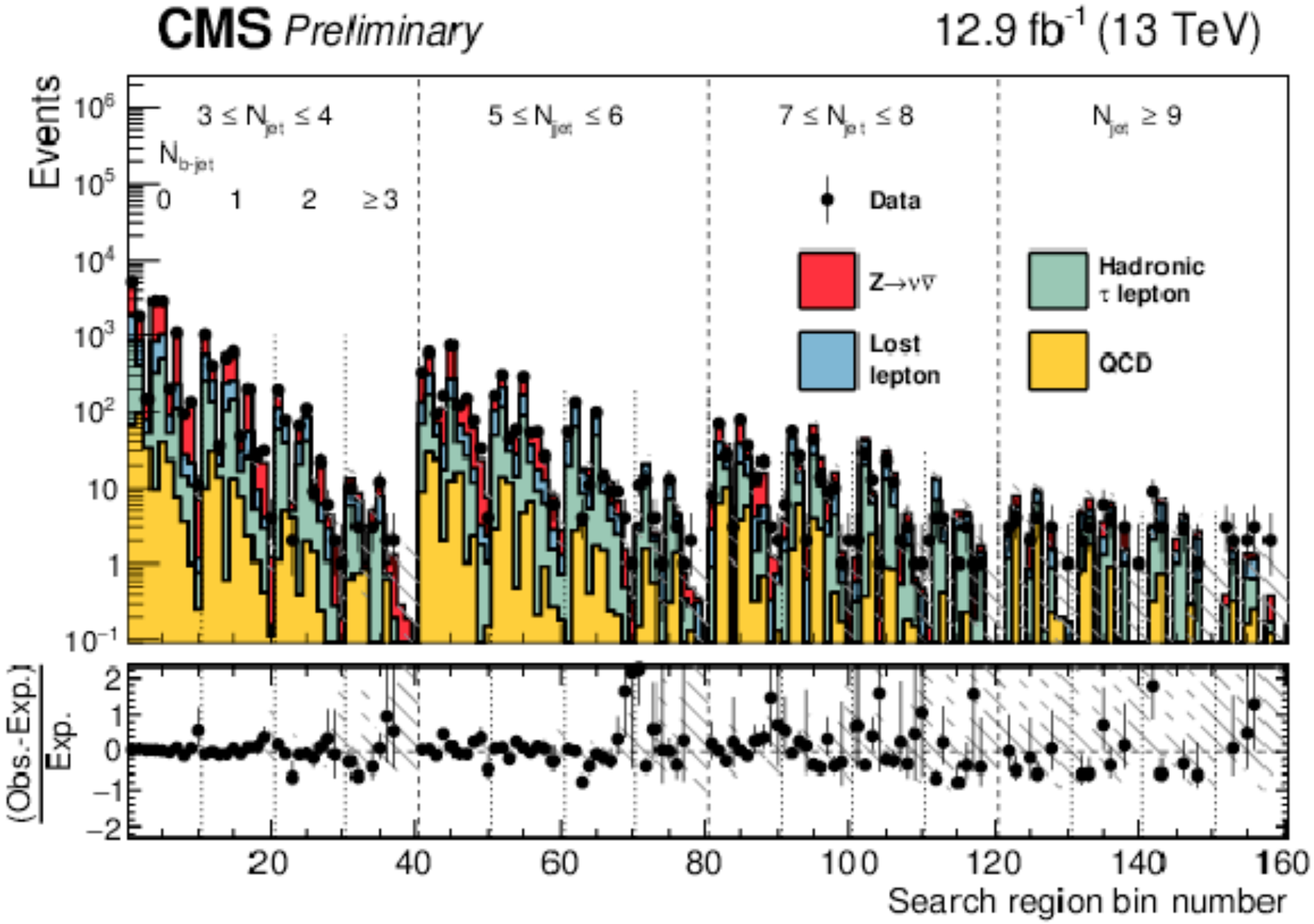


Search for SUSY in Jets+MET

CMS PAS SUS-16-014

Backgrounds grouped by features

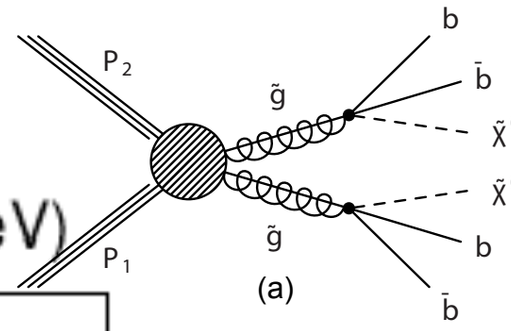
- ➢Z→νν
- ➢Lost lepton
- ➢Hadronic-tau lepton
- ➢QCD

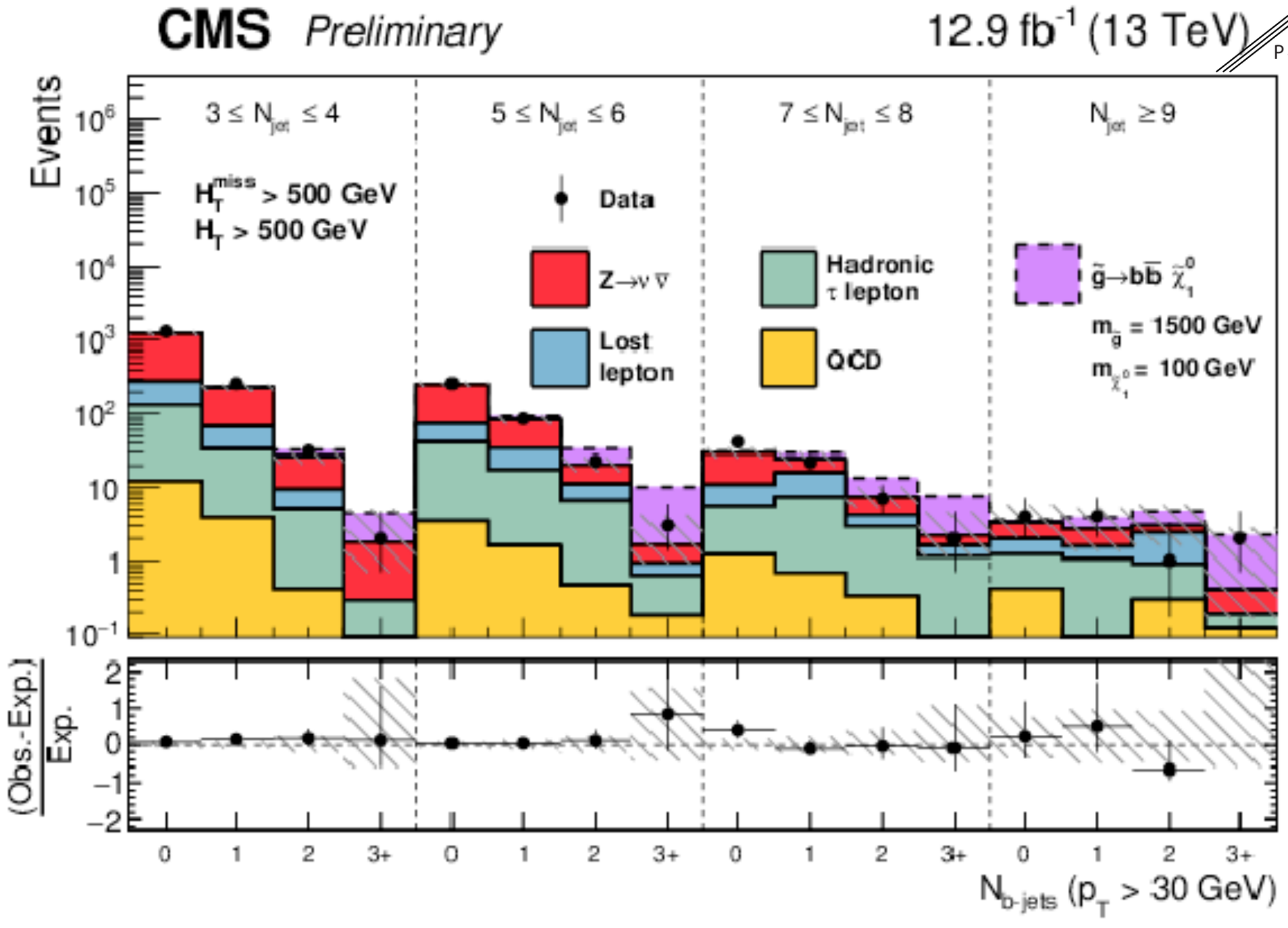


Search for SUSY in Jets+MET

CMS PAS SUS-16-014

Example sensitivity to T1bbbb



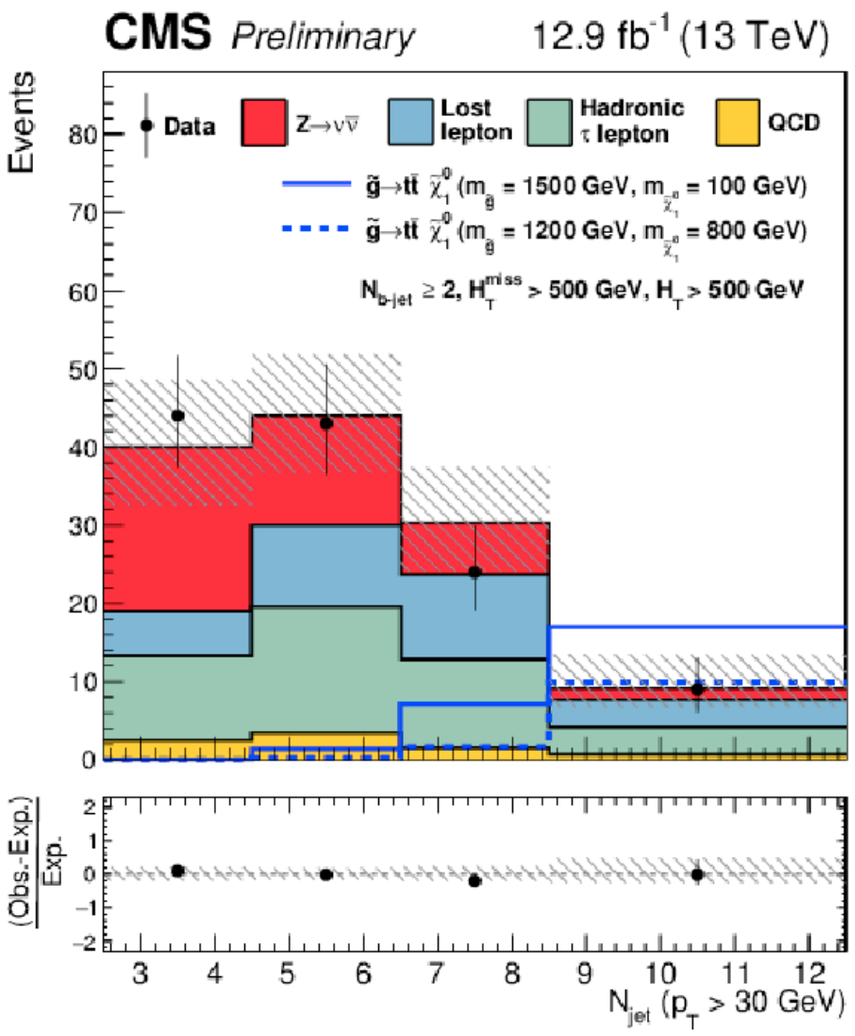


Search for SUSY in Jets+MET

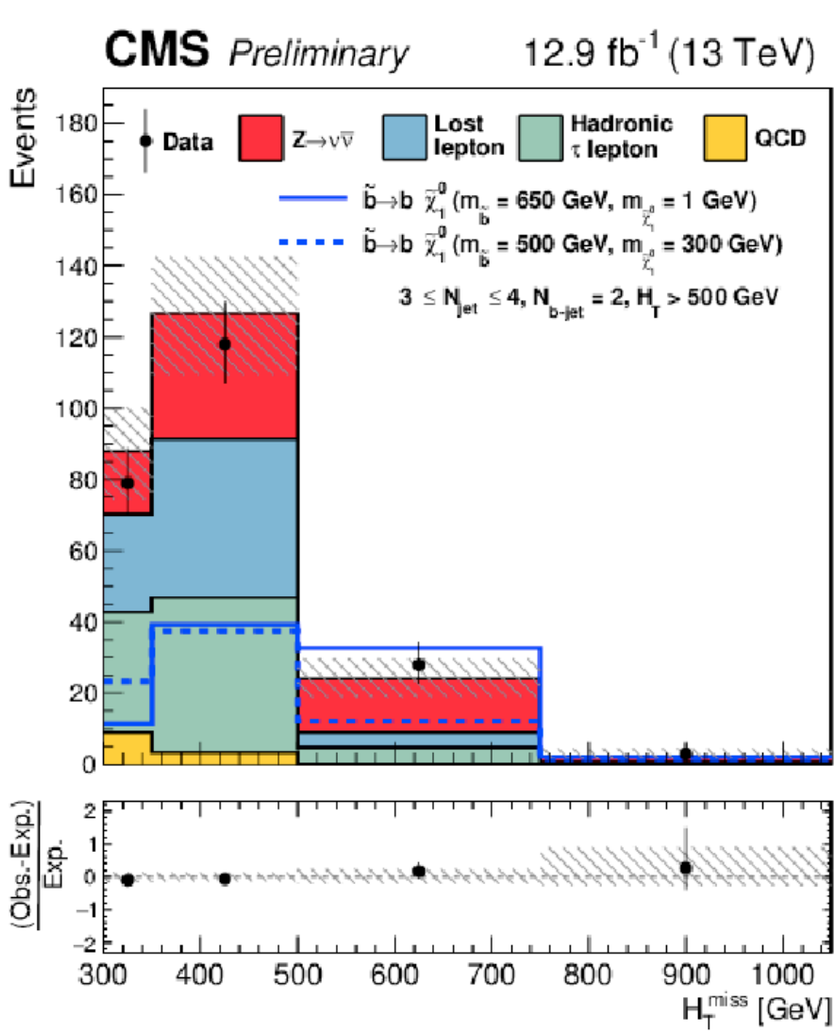
CMS PAS SUS-16-014

Other specific regions sensitive to:

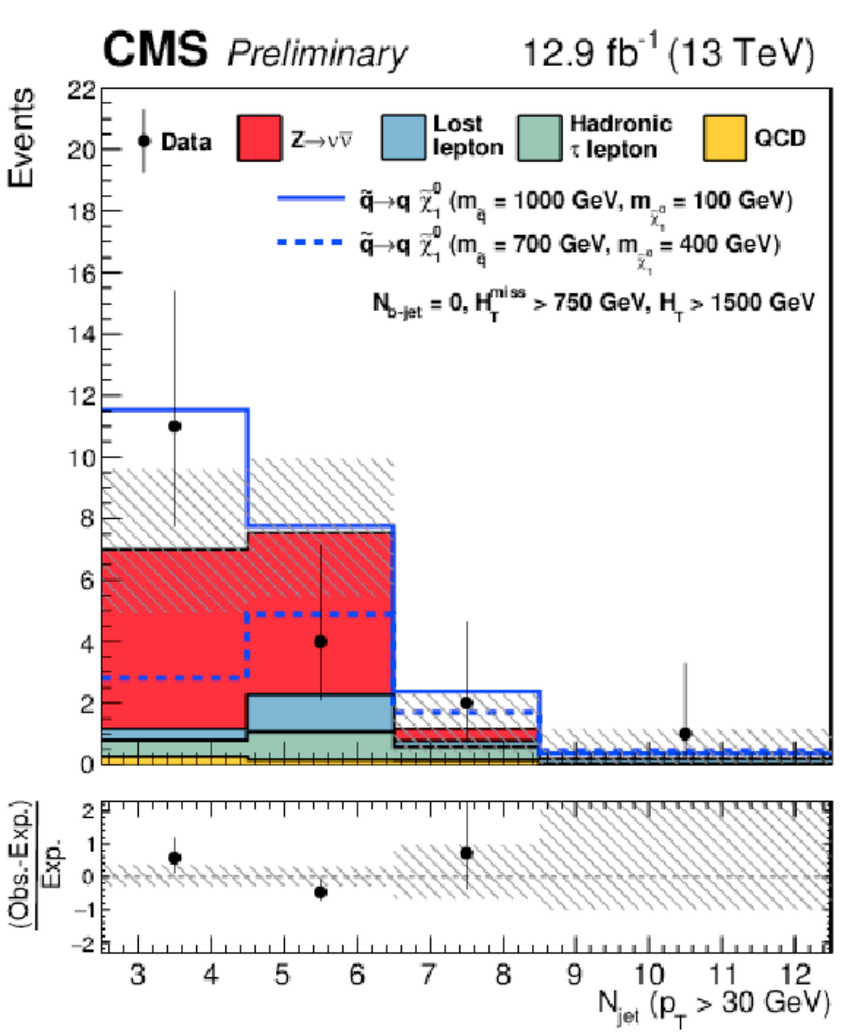
➢T1tttt



➢T2bb



➢T2qq

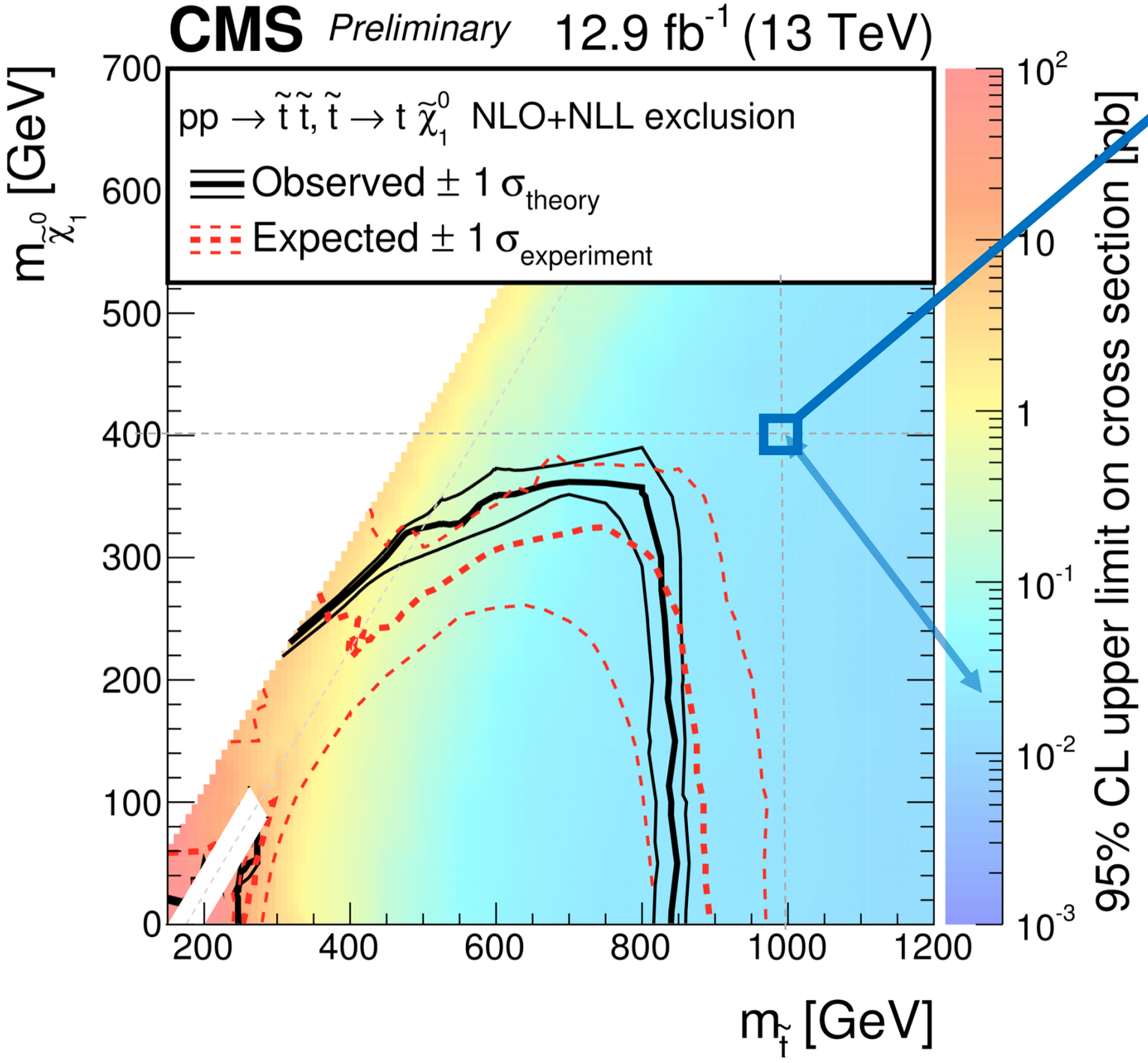


Great sensitivity to many different scenarios

Search for SUSY in Jets+MET

CMS PAS SUS-16-014

Example exclusion results

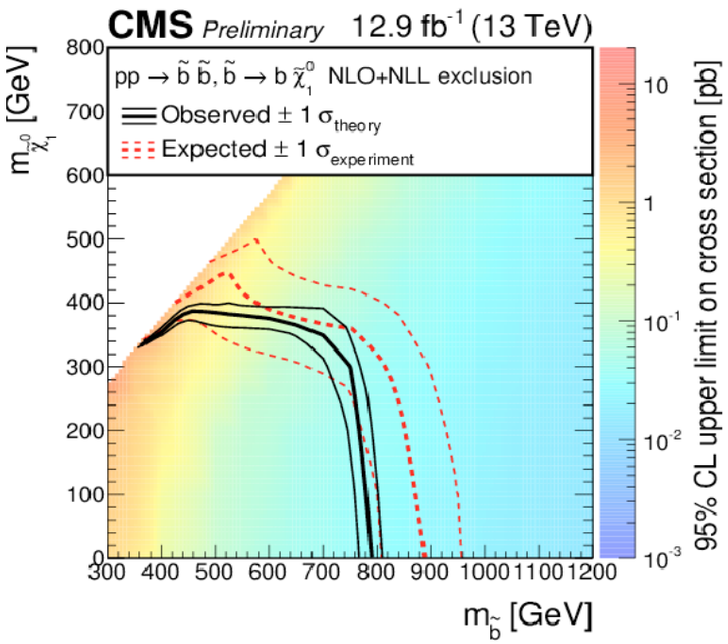


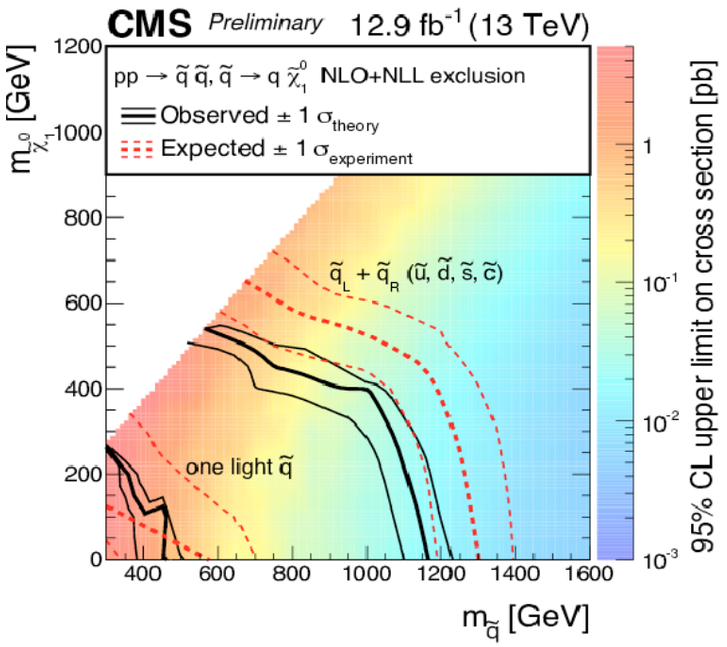
- 95% CL upper limit in XS @ (1000,400) = 0.02 pb
- We can exclude at 95% C.L. production wherever expected cross section is larger than upper limit.
- At (1000,400) production is ~0.006 pb so we can't exclude that point.

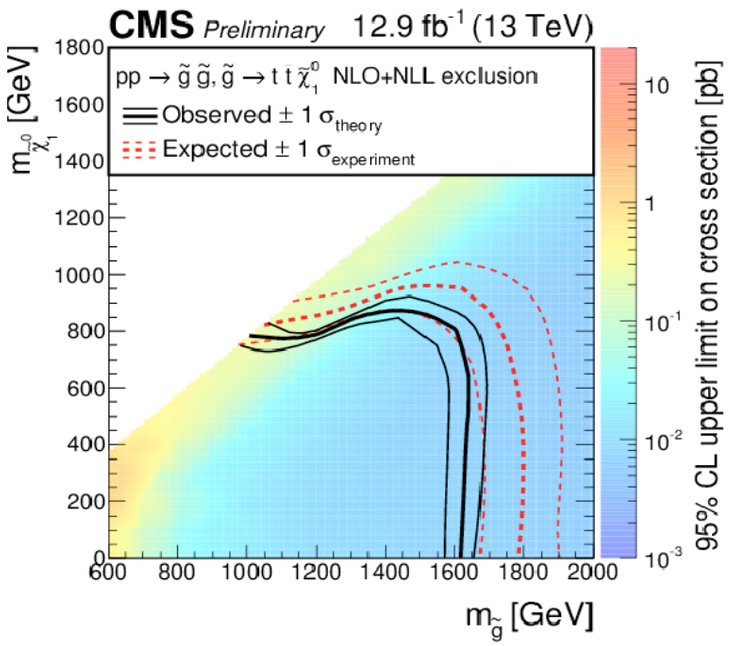
Search for SUSY in Jets+MET

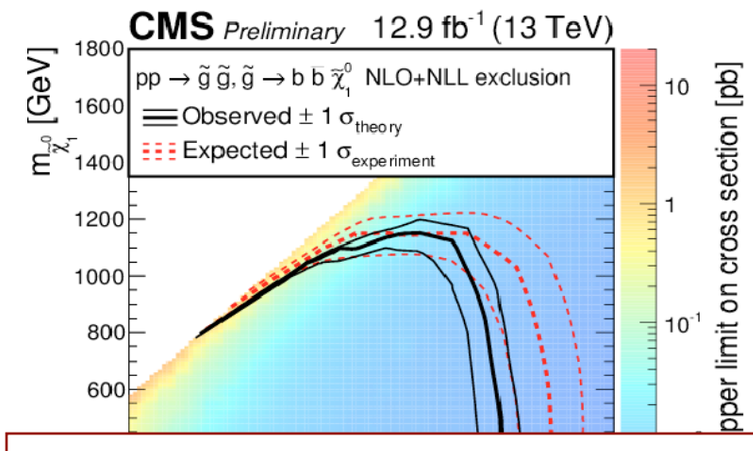
CMS PAS SUS-16-014

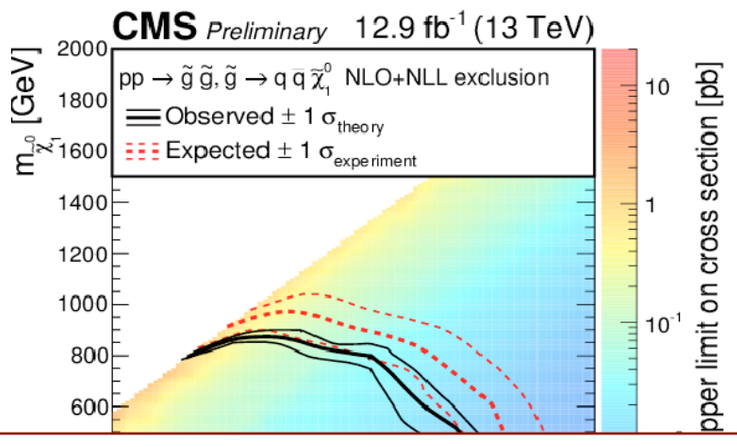
Reminding Results

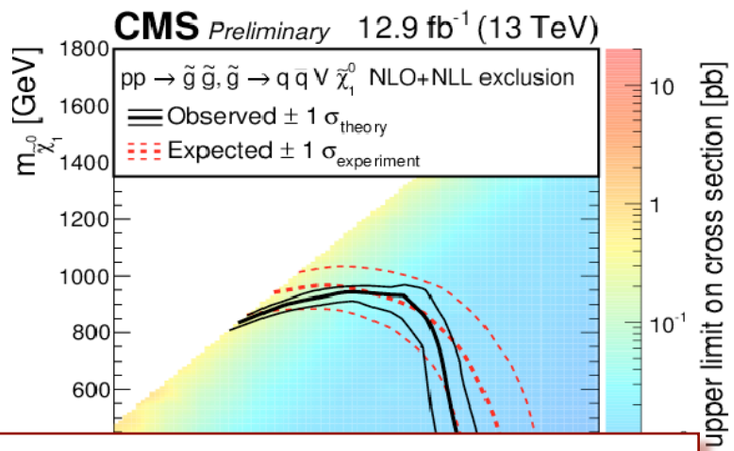






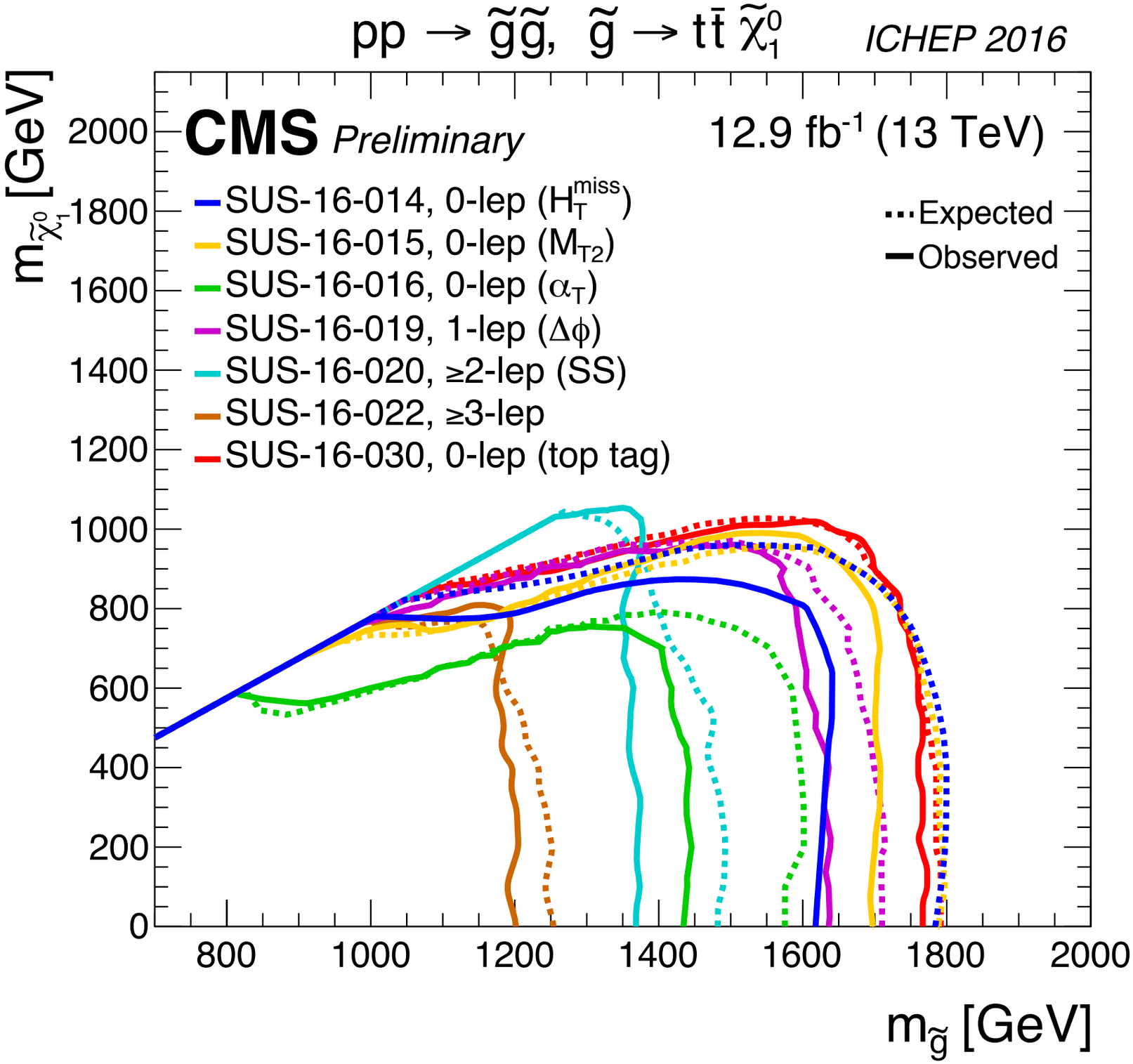


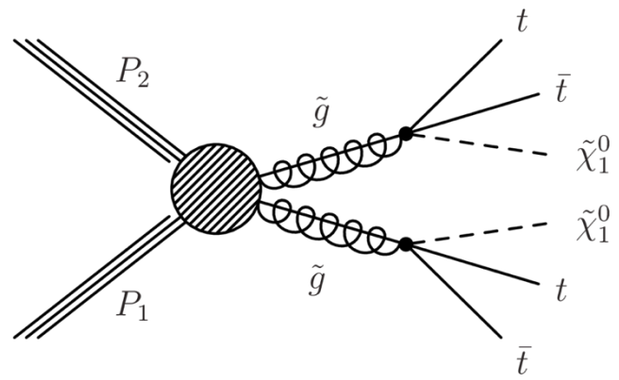




Added luminosity extended sensitivity region by 100-200 GeV

SUSY : Combining with leptons





Summary

- Fantastic show of CMS results at ICHEP 2016
  - More than 70 new results enabled by the successful operation of the LHC and CMS detector.
- Broad scan of physics beyond the SM.
  - More data help achieved new levels of sensitivity
  - Great increase in reach of BSM
- No significant deviation from the SM… **just yet…**
- CMS is collecting data like crazy
  - As of today have 20 fb^{-1}, expect ~26 fb^{-1}on 2016.

Stay tuned for the next set of results from the LHC

Thank you

Backup

In 2015 LHC went from $\sqrt{s}$= 8 TeV to 13 TeV …